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Evaluation of Color Infrared Aerial Surveys of Wastewater Soil Absorption Systems

Urban Systems Research and Engineering, Inc.
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EVALUATION OF COLOR INFRARED AERIAL SURVEYS OF WASTEWATER SOIL ABSORPTION SYSTEMS

by

Susan O. Farrell
Urban Systems Research and Engineering, Inc.
Cambridge, Massachusetts 02138

Contract #68-03-3057

Project Officer

Robert Bowker
Wastewater Research Division
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The U. S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report discusses the usefulness of color infrared (CIR) aerial photography in locating failing wastewater soil absorption systems. The information presented is the result of literature search and interviews with numerous users of CIR aerial surveys. CIR theory and effectiveness as well as recommended survey procedures are presented.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

Color infrared (CIR) aerial surveys can be used to identify soil absorption systems in which the effluent is rising to the surface rather than percolating into the ground water. This report reviews the technique's scientific basis and effectiveness. It also describes the procedures and equipment required for such surveys, and survey costs.

CIR aerial photography reveals differences that are invisible to the naked eye and cannot be seen in color images in vegetation over excessively ponded or surfacing soil absorption systems. Experienced interpreters can review the images to identify the systems that appear to be failing, and then verify the existence of these failures through ground inspections. Standard photogrammetric mapping cameras and procedures with color infrared film should be used to obtain the images.

The analysis relied on review of the literature on CIR aerial photography in general, as well as the limited published information on CIR aerial septic system surveys. In addition, the practitioners and clients of the CIR aerial surveys were contacted. The research revealed that CIR aerial surveys are less expensive and more accurate than other surveying methods. The false positive rate is high so that ground verifications must be an integral portion of any survey, but properly conducted CIR aerial surveys missed very few soil absorption systems that were surfacing. The technique is limited to onsite system failures that involve surfacing effluent.

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CHAPTER ONE

INTRODUCTION

1.1 DESCRIPTION OF CIR AERIAL SURVEYS

Color infrared (CIR) aerial photography can be used to identify onsite wastewater soil absorption systems (SAS's) where the septic tank effluent is rising to the surface rather than percolating into the groundwater. SAS failures of this type pose a potential threat to public health and surface water quality. In extreme cases installation of centralized sewage collection and treatment may be required. In less severe situations communities may need to develop management systems to insure the proper operation and maintenance of existing onsite wastewater systems. Traditionally, water quality planners and engineers have identified surfacing SAS's through the use of ground inspections or mailed questionnaires. However, the first method can be time-consuming and expensive, while the second provides unreliable and incomplete information.

Recently, aerial photography has been proposed as an alternative method. The technique involves taking CIR photographs of communities and examining the images for the characteristic "signatures" of surfacing SASs -- outbreaks of effluent or patches of dead vegetation surrounded by patterns of lush vegetation outlining the septic tank effluent distribution lines. When surfacing effluent reaches the root zone, it promotes the growth of overlying vegetation through irrigation and fertilization. However, if the effluent remains ponded around the roots for too long, it drowns the roots and kills the plants over the SAS. Because CIR film is more sensitive than the naked eye (or conventional color film) to differences in vegetation density and health phenomena, CIR images enhance these surface manifestations of SAS failures.

CIR aerial photography can only be used to identify SAS failures which lead to surfacing effluent. Thus, CIR aerial surveys can detect broken distribution lines, leaching septic tanks, diverted distribution lines, and leaching fields with ponding effluent, but the method cannot identify systems that back up into homes or discharge inadequately treated effluent into groundwater.

CIR aerial surveys have been used in wastewater management planning. The results have helped to document the need for centralized wastewater treatment facilities or improved management systems, and to document the role of surfacing SAS's in lake eutrophication. To date, EPA regional

Environmental Impact offices have made the most use of the technique as a part of the 201 facility planning process, but states and county governments are increasingly contracting for these services independently.

Two EPA Environmental Monitoring and Support Laboratories (EMSL) currently perform CIR aerial surveys at EPA's regional offices: The Environmental Photographic Interpretation Center (EPIC) in Warrenton, Virginia, and EMSL in Las Vegas, Nevada. Both laboratories rely on private contractors to obtain and interpret the aerial CIR photographs. In addition to these labs, several environmental consulting firms offer CIR aerial survey services, and a few sanitary engineering firms have performed CIR aerial surveys in-house as a component of the planning and evaluation process for ongoing wastewater management projects.

1.2 ISSUES CONCERNING CIR AERIAL SURVEYS

Because the use of CIR aerial surveys to detect surfacing SAS's has evolved over the past few years, the technique's theoretical basis, effectiveness and methodology have never been comprehensively evaluated or explained. The purpose of this report is to answer questions concerning these issues. Specifically, the report provides information on the following topics:

- the scientific basis for the technique, including what the CIR film is recording, why it is particularly sensitive to surfacing effluent, why it is preferred over other types of film, what the surface manifestations of surfacing onsite systems are, and why and how these signatures occur

- the effectiveness of the technique, including the types of failures it can identify, the number of properly operating systems that appear to be failing in the CIR photographs (the false positive rate), the number of failing systems that are missed in a CIR aerial survey (the false negative rate), the cost, and the circumstances affecting each of the above concerns

- the proper procedure for CIR aerial surveys, including the choice of camera, film, image overlap, scale, season, time of day, and weather conditions for the photography, as well as the necessary background information and interpretation and verification techniques.

1.3 METHODOLOGY

The report relies on published and unpublished materials and extensive interviews. The documents of particular value are an EPA-supported master's thesis by Leonard Crouch which reports early research into the CIR aerial survey procedures and the power of the technique, and the American Society of Photogrammetry's Manual of Remote Sensing, Volume II, edited by Reeves, Anson, and Landen.

Officials at the three organizations most experienced with the technique were interviewed: the two EPA monitoring laboratories and a private firm, Remote Sensing Consultants. Project staff also contacted other practitioners including Richard Pavey of the Laboratory of Remote Sensing at Purdue University, Bud Morlock of Flying Cameras Inc., Enon, OH, Clyde Williams Associates, of South Bend, IN and Midstate Engineers Inc. of Indianapolis, IN.

In addition, representatives of 32 of the 34 identified CIR aerial survey client communities were interviewed. Finally, experts in the field of aerial color infrared photography at Eastman Kodak Corporation, Purdue University, Pennsylvania State University, and University of Wisconsin were also interviewed. Appendix A is a complete list of the individuals contacted.

CHAPTER TWO

CONCLUSIONS AND RECOMENDATIONS

2.1 VALUE OF CIR AERIAL SURVEYS

Color infrared (CIR) aerial surveys are a valuable tool for locating soil absorption systems (SAS's) in which the effluent is rising to the surface rather than percolating into the ground. The technique involves examining aerial color infrared photographs of communities for the characteristic signs of surfacing SAS's: pools of water or patches of dead vegetation surrounded by lush growth. Because CIR film is uniquely sensitive to differences in vegetation density and the presence of moisture, the "signatures" of ponding SAS's are enhanced in the images. However, because other phenomena can mimic the signs of surfacing effluent, the interpretations should be verified through ground observations of all SAS's that appear to be failing.

CIR aerial surveys can help engineers and communities to evaluate the severity of the problem and assess the need for improved management or replacement of existing onsite systems. CIR aerial surveys have several advantages over house-to-house, or mailed surveys. Complete CIR aerial surveys are relatively inexpensive. Past surveys cost from $.79-$10.34/house depending upon the size of the survey, the kind of services provided, and the surveyor. CIR aerial surveys are also quick, non-labor intensive, and because they do not require the cooperation of the homeowner, it is possible to obtain information on every household in the area of concern.

Experience indicates that when trained personnel interpret the photographic images, very few properly operating SAS's are mistaken for failing systems. Similarly, clients reported that they have found very few failing SAS's which were not revealed in the survey. This claim is subject to some question, because there has been no concerted attempt to locate additional failures after the completion of a CIR aerial survey.

2.2 THEORY

CIR aerial surveys have a sound scientific basis. Both the characteristic signs of surfacing effluent and the effectiveness of CIR film in detecting these signatures are supported by theory and experience.

When ponding effluent reaches the root zone of the overlying plants it provides extra nitrogen and moisture. Initially, this subsurface fertilization and irrigation promotes lush plant growth directly over the SAS. However, if the effluent pools on the surface or saturates the root zone for a few weeks, the roots eventually drown and the surface vegetation dies. Usually nothing will grow in the area after the effluent subsides unless the soils are replaced and the area reseeded. This process results in the classic signs of a surfacing SAS -- pools of effluent or patches of dead vegetation coupled with lush plant growth mimicking the layout of the distribution lines.

Because CIR film records near infrared electromagnetic wavelengths (700-900 nm) as well as some visible (400-700 nm) wavelengths, it is more sensitive than the naked eye to the signs of surfacing effluent. Depending on the species, plants reflect from two to nine times as much near infrared radiation as visible radiation. A given change in the vegetation results in a greater absolute change in the amount of near infrared reflected than in the amount of visible light. As a result, CIR photographs reveal variations in the density and lushness of vegetation invisible to the human eye, and not recorded on conventional color aerial photographs.

Because the health and age of a plant affects the amount of CIR radiation it reflects, patches of healthy or luxuriant areas are easily distinguished from areas of dead or stressed vegetation in CIR images. Similarly, since water reflects almost no CIR radiation, pools of effluent show up as well defined patches of black or dark gray in the images. Thus an experienced interpretor can review CIR photographs and readily identify those lots that appear to exhibit signs of failing SAS's.

Several studies support the effectiveness of CIR film in the evaluation of vegetative growth and its sensitivity to the signs of surfacing (Crouch, masters thesis). Its superiority to conventional color, black and white, and thermal IR film for this purpose is also well documented (Thorley, 1975; Lauer, 1968; Anson, 1970; Tuyahov and Holz, 1973).

Only images that show signs of present or past surfacing -- pools of water or patches of dead vegetation -- can be positively identified as SAS failures. Shallow SAS evapotranspiration systems may exhibit lush vegetation characteristic of surfacing effluent despite the fact that the SAS's are not malfunctioning. Lush vegetation alone does not necessarily indicate SAS "failure". Similarly, yard artifacts such as large rock formations, puddles, and gardens, can mimic the signs of failing systems, and interpretation requires considerable experience.

CIR aerial surveys have several limitations.

- o They can only locate SAS failures that involve surfacing effluent. Systems where effluent is backing up into the home, is inadequately treated before it reaches the groundwater, or is illegally piped to surface water cannot be identified.

- They will not reveal surfacing effluent if the line of sight between the SAS and the camera is blocked. These surveys will have limited effectiveness in areas with many evergreen trees or in forested areas when the trees are in leaf. Shadows may also obscure failures.

- They will locate intermittently failing systems only if the characteristic failure signature is present at the time of photography.

2.3 RECOMMENDATIONS

2.3.1 Best Practices

Best practice for CIR aerial surveys involves successful completion of the following five steps.

Survey Preparation involves obtaining background information on the soils, system design, groundwater depth fluctuations, and topography maps of the survey area. Such information is readily available and necessary to lay out flight lines, determine flight dates, and evaluate the survey results.

Image Acquisition involves completing the aerial photography. Since standard equipment and procedures are used, any experienced aerial photographer could perform this part of the survey. CIR film is readily available and can be processed in-house or at several laboratories around the country. Although various practitioners of CIR aerial surveys disagree somewhat about proper equipment and technique, research indicated that the following procedures offer the best survey results.

- Film CIR is the film of choice, and Kodak Aerochrome 2443 is the only low altitude aerial CIR film available. Color and CIR film are sometimes used simultaneously because inexperienced interpreters find it easier to recognize the factors that mimic the signs of surfacing effluent on color images than on CIR images. However, because experienced interpreters do not need this assistance, and only experienced interpreters should be used, color film is an unnecessary added expense.

- Cameras Standard photogrammetric mapping cameras used by aerial photographic firms provide the least costly coverage of the survey area. Flying time, film costs, and interpretation costs increase if 35 mm cameras or EPA's ENVIRO-POD camera system is used. Filters must be used with CIR film to screen out blue wavelengths. Wratten 12 filters provide the best contrast.

- Photography Standard photogrammetric mapping procedures give the best results for the lowest price. These include 60% image forward lap for stereoscopic viewing and 30% sidelap to insure coverage of the area.

- o Scale Scale is the ratio of the distance on the film to distance covered on the ground. It is calculated from the ratio of the lens focal length to the altitude of photography. A maximum scale of up to 1:4000 can be obtained with standard aerial photograhy equipment if the plane flies at FAA's 1000' minimum legal altitude over residential areas. Because the number of images required to cover an area increases with the square of the increase in scale, it is important to keep the scale as small as possible to minimize costs. However, scales should be as large as possible to maximize ground resolution. Experience with CIR aerial surveys indicates that 1:8000 appears optimal from the standpoint of cost and image resolution.

Interpretation involves analyzing the images and identifying failing systems. Color transparencies should be analyzed using a light table, and a standard pocket stereoscope with 4 fold magnification.

Although standard image interpretation techniques and equipment are used, experience with CIR aerial surveys indicates that interpreters must be familiar with CIR film, SAS design, and the signatures of surfacing SAS's. Inexperienced interpreters may miss failing systems and may mistake properly operating SAS's for failing systems.

Ground Verification involves inspecting suspected failures to make sure that image interpretation was accurate. This is a necesary component of CIR aerial surveys. This step is necessary because some ground artifacts may be mistaken for surfacing systems, and the signatures of failing SAS's will vary with system design and soil type. This step can be completed by the community, the engineer, or the surveyor. The proportion of systems to be inspected depends on the purposes of the survey. If it is necessary to quantify the exact number of failures, all suspected failures must be inspected. If, on the other hand, the survey is intended to assess the general suitability of an area for onsite wastewater systems, it is possible to inspect a representative sample of suspected failures to insure that the interpretation key was accurate. At least 10% of the suspected failures in a given soil type, of a certain design, or of a certain age should be verified. The task should be peformed as soon after the survey as feasible, so that conditions are as similar as possible to those at the time of the photography.

Report Writing involves packaging the results so that they are useful to the client.

2.3.2 Research Needs

Although the technique is well grounded in theory and is well proven in practice, some aspects of the effectiveness of the technique could benefit from further research. These include:

- o documentation of the false negative rate through controlled experiments

- determination of the duration of the ground manifestations of surface outbreaks and the factors affecting that period
- identification of soils in which capillary action promotes lush vegetation when the systems are properly operating
- an assessment of the technique's potential for identifying discharges to lakes.

CHAPTER THREE

THEORY

3.1 INTRODUCTION

This chapter discusses the theory of using aerial color infrared (CIR) photography to locate failing soil absorption systems (SAS's). CIR film can record the dead vegetation, excess vegetation, and pools of effluent which are characteristic of continuously or intermittently surfacing effluent. This chapter focuses on the following topics:

- o surface manifestations of exessively ponded SAS's
- o principles and advantages of CIR photography, compared to other films
- o the photographic "signatures" of ponding SAS's
- o possible factors that can mimic or mask these signatures
- o limitations on the use of CIR aerial surveys.

3.2 SURFACE MANIFESTATIONS OF EXCESSIVELY PONDED EFFLUENT

CIR aerial surveys can be used to detect surfacing effluent because of the effluent's impact on the vegetation above the SAS. Ponding occurs when the instantaneous rate at which effluent is added to the SAS exceeds the rate at which it can pass through the soil infiltrative surface to the groundwater. In excessively ponded SAS's, effluent accumulates in the SAS until it breaks out on the surface where it pools, evaporates, or flows away.

A number of factors may cause effluent to surface:

- o undersizing of the SAS relative to the amount of effluent being discharged and the acceptance rate of the infiltrative surface
- o improper construction practices causing smearing or compaction of SAS bottom and sidewalls
- o a break or blockage in the distribution lines causing reduction in effective SAS size

- o clogging mats which may become too restrictive to accept the volume of effluent discharged

- o high groundwater saturation of soil so as to temporarily eliminate or restrict the passage of effluent through the SAS

- o system location in or near an impervious soil layer.

While not related to the design or effectiveness of the SAS, a leak or stoppage in the septic tank or the release of wastewater directly to the soils surface may also cause wastewater to affect surface vegetation.

In the most severly ponded systems, effluent breaks out on the surface. However, ponding effluent has surface manifestations as soon as it reaches the root zone, approximately six inches below the surface for most common yard grasses although hardy fescues such as Kentucky 31 or Alta may have 12-inch root systems (Hill, personal communication). Because the septic tank effluent provides the plants with subsurface irrigation and fertilization, lush growth appears over ponded systems.

Excess vegetation can be found directly over the SAS or in plumes that reflect the lateral movement of the effluent (Lumsden, personal communications). The lushness over excessively ponded SAS's first appears in the early spring, when the soils are relatively saturated with rainwater. Usually it takes about three weeks after the effluent subsides below the root zone for the vegetation to return to normal.

Excessive ponding or surfacing can also kill the surface vegetation. When effluent saturates the root zone or remains pooled on the surface for two or more weeks, the roots become oxygen-starved and eventually drown (Lumsden, personal communication). The plants do not usually come back to life after extended surfacing episodes because of a phenomenon called "burn-out". Septic tank effluent has high levels of nitrogen salts which are left behind in the soil as the effluent subsides. When too much nitrogen is present, the soil becomes acidic. Acidity hinders new growth and promotes plant disease. Because of burnout, reseeding alone will not usually restore a lawn after it has been killed by surfacing effluent. New grass will not normally survive until the soils are replaced. It takes about four weeks after the soil is rejuvenated and the lawn reseeded for grasses to return (Lumsden, Hill, personal communication).

3.3 CIR PHOTOGRAPHY

3.3.1 Principles

Aerial CIR photography is sensitive to the changes in grass density resulting from surfacing effluent. The reason for the films sensitivity rests in the wavelengths it records. Unlike conventional color films which only record the visible spectrum (250-700nm), CIR film records both near (also referred to as nonthermal or color) infrared and visible wavelengths. Exhibit 3-1 shows the sensitivities of various film types.

Exhibit 3-1

WAVELENGTHS RECORDED BY DIFFERENT FILMS

Conventional Color	250-675 nm
Color Infrared	400-900 nm
Thermal Infrared	500 nm - 10 μm

(visible wavelengths: 400-675 nm)

As shown in Exhibit 3-2, grasses (and other plants) reflect significantly more radiation in the near IR wavelengths than in the visible spectrum. Additionally, the amount of reflected near IR varies with vegetation health and age. Near IR reflection is directly proportional to the amount of interstitial air space and chlorophyll and indirectly proportional to the amount of water contained in the leaves. Since these factors depend on plant age and health, healthier and older plants reflect more near IR light than young or unhealthy plants (Myers, 1975).

Because of the differences in near IR reflection, patches of excess vegetation that would be barely visible in color images show up clearly on CIR photographs. Dead vegetation and bare spots on the yard are also clearly visible. Pools of effluent are also readily apparent, since water absorbs almost all incident near IR radiation. However, these features have different colors in CIR images than in nature. CIR film is also known as "false color" film because the colors in the images differ from those perceived by the human eye. Exhibit 3-3 shows the color shift that occurs with CIR film and the appearance of the different surface manifestations of surface failure in the images.

3.3.2 Theoretical Advantages of CIR Film

CIR Versus Color

CIR film is more sensitive than the naked eye or color film to variations in the types and density of vegetation and to the presence of surface outbreaks of effluent. Three factors contribute to this sensitivity.

- As shown in Exhibit 3-2, grass reflects almost nine times as much near IR as visible radiation. A change in the characteristics of the vegetation would have nine times the impact on the near IR radiation reaching the camera as on the amount of visible radiation reaching the camera.

- A given change in vegetation density will have a greater impact on the amount of near IR radiation reflected than on the amount of visible radiation reflected (Myers, 1975). Not all incident radiation is reflected by a leaf: some is absorbed and some passes through the leaves to be absorbed or reflected by the leaves below. Leaf Area Index (LAI) is the number of leaf layers needed to achieve the maximum reflectance. Leaves allow more near IR radiation than visible radiation to pass through to lower layers. Plants have an LAI of 2 in the visible wavelength, and 8 in the infrared. Therefore CIR can record eight different leaf densities while color film can only record two.

- CIR film is less sensitive to haze and atmospheric pollution than color film (Eastman Kodak, 1977).

Exhibit 3-2

PERCENT SPECTRAL REFLECTANCE OF
GRASS AT DIFFERENT WAVELENGTHS

Wavelength	% Reflectance
400 nm (violet)	1%
550 nm (yellow-green)	11%
650 nm (red)	2%
700 nm (near infrared)	30%
800 nm (near infrared)	90%

Source: Estes and Simonett

EXHIBIT 3-3

APPEARANCE OF SURFACE MANIFESTATIONS OF FAILURE ON CIR FILM

Manifestation	Natural Color	CIR Color
Lush Vegetation	Green	Bright Red
Weak Vegetation	Green	Dull Red
Dead Vegetation	Brown	Brown/Gray
Pools of Effluent	Blue/Gray/Black	Black

While CIR film is more sensitive than color film to differences in plant lushness and type, the difference between dead and healthy vegetation is somewhat clearer on color film than on CIR. There are two reasons for this phenomenon.

- The difference in the amount of visible light reflected by stressed and healthy vegetation is proportionately greater than the difference in the amount of near IR light reflected by stressed and nonstressed vegetation (Myers, 1975).

- Because of the loss of chlorophyll which absorbs visible light and a decrease in CIR reflectance, dead plants will reflect almost as much visible light as CIR light (Knipling as cited in Myers, 1975).

Although color film is able to record the differences between stressed and healthy vegetation in a greater range of color shades and intensities than CIR film, CIR film is superior for surveying SAS's. First, the dead vegetation can be easily spotted in CIR images. More importantly, the lush vegetation is the first and most powerful clue that the system may be failing. This causes the interpreter to examine the yard more closely. The lush vegetation also allows the interpreter to locate the system and distinguish random pools of water or patches of dead vegetation or other artifacts which could be mistaken for surfacing effluent from genuine failures. Excessive lushness is not readily apparent on color film: each yard would have to be examined much more closely. It is likely that many more failures would be missed, and many properly operating SAS's would be mistaken for failing systems.

CIR Versus Other Films

Other types of film are also commonly used in aerial screening including black and white, black and white IR, and thermal IR (TIR). These films are less sensitive to the signs of surfacing effluent than color or CIR film for two reasons. First, these films record only in shades of gray. The human eye can only detect 200 different intensities of gray whereas it can detect 20,000 different shades, hues, and intensities of color (Evans as cited in Estes and Simonett, 1975). In addition, CIR and color film both have better resolution capabilities than either black and white or black and white IR film (Harris, et.al., as cited in Estes and Simonett, 1975).

3.3.3 Experimental Evidence

Many studies have shown that the speed and accuracy of aerial interpretation of vegetation characteristics is improved when color film is used in place of black and white (Thorley, 1975). Remote sensing studies since the 1960's have all indicated that CIR is superior for interpreting changes in vegetation density and for distinguishing among types of vegetation. Tuyahov and Holz (1973) compared thermal IR, color IR, and color imagery to analyze vegetation and land use patterns on a barrier island and found CIR to be superior. Similarly, Fritz, (as cited in Estes and Simonett, 1975) showed that CIR was superior for the differentiation of

areas of low and high vegetation density and stress than color or black and white. Pease and Bowden (as cited in Estes and Simonett, 1975) found that CIR was less affected by haze than was color film.

Additional evidence supports CIR's superiority over color in the particular field of SAS screening. Leonard Crouch's masters thesis concerns the use of TIR, CIR, and color imagery of failing SAS's. He conducted aerial surveys of two areas in Ohio, one of which was known to have a high proportion of surfacing leaching fields. The other area served as a control and had few failures. Crouch's research revealed that differences in lushness showed up vividly on the CIR images but were difficult to discern in the true color images. EPA had the same findings in similar unpublished experiments (Crouch, unpublished masters thesis). As expected, Crouch also found that it was easier to distinguish between dead and healthy vegetation on the color images than on the CIR images.

Crouch and EPA also tested the efficacy of thermal infrared photography (TIR). TIR measures heat radiation -- the wavelengths above 500 nm. TIR film is not used to differentiate the density of vegetation, but to detect the surfacing effluent directly. Because water and soil have different specific heats, they will heat and cool at different rates and, except when in equilibrium, will emit different amounts of TIR radiation. Thermal scanners detect these differences and record them in differing shades of gray. Due to increased water content, soils over failing septic tanks will be a different temperature than the rest of the yard and show up on TIR images.

Crouch and EPA found that yards with failing leaching fields had different thermal scans than yards with properly operating systems. Crouch's experiments also revealed that daytime scans were less informative than nighttime scans because shadows and localized heating by the sun had the same magnitude of effect as soil moisture markers, which made it difficult to distinguish the clutter in the photograph from failing septic systems. Although failing SAS's were apparent on nightime scans, CIR and color photography were needed to confirm their presence. EPA found similar results when they tested the three methods and concluded that CIR and color photography gave a better indication of the presence of failing systems.

3.4 PHOTOGRAPHIC SIGNATURES OF FAILING SEPTIC SYSTEMS

Practitioners of CIR aerial surveys have defined three different signatures which correspond to three degrees of onsite system failure.

- o Overt Failure Signatures are seen when systems are failing at the time of photography. Pools of nutrient-rich water (gray or black in the images) are usually surrounded by lush (bright red) vegetation outlining all or part of the SAS distribution lines. A stream of effluent or lush vegetation flowing downhill from the SAS lines may be evident.

- o Seasonal Failure Signatures are seen when systems fail periodically, but are not failing at the time of photography. Patterns of lush vegetation over the SAS distribution lines and patches of dead vegetation (tan) where past outbreaks have occurred are characteristic of these signatures.

- o Seasonal Stress Signatures can be indicative of SAS's that may be in danger of failing or are severely stressed. They consist of lush vegetation over all or part of the leaching field. These signatures should be interpreted cautiously since they do not necessarily indicate that a system has failed or will fail. In some soils, effluent may reach the root zones as a result of capillary action. This is most likely to occur with systems that maximize evapotranspiration, with shallow SAS's, and with SAS's located in fine textured soils. When seasonal stress signatures appear in areas where there are also several seasonally or overtly failing SAS's the suitability of the area for SAS's should be questioned.

Overtly failing systems remain visible on the ground all year (unless covered by snow) because pools of moisture are always present and the vegetation has no chance to recover. Because seasonal stress and seasonal failure signatures depend on the difference between the vegetation over the SAS and the rest of the yard, they are only apparent during the growing season. The additional nutrients and moisture prolong the growing season somewhat, so changes in vegetation density and health would become apparent in early spring and would remain visible late into the fall.

3.5 FACTORS THAT MIMIC OR MASK SIGNATURES

There are several factors that can mimic the photographic signatures of past or present outbreaks of effluent.

- o Features that absorb near IR radiation can be mistaken for the pools of effluent or dead vegetation characteristic of overtly failing SAS's. Examples include exposed soil, compost heaps, garden plots, basketball courts, outcroppings of rock, and yard trash burning pits.

- o Natural pools of water such as springs, bogs, or puddles in low lying areas can also be mistaken for surface outbreaks.

- o Other sources of moisture such as sump pump discharge points, leaking garden hoses, downspouts, runoff from feed lots, or erratic fertilization can promote vegetation patterns like those caused by surfacing septic tank effluent.

However, trained observers can use many subtle clues to distinguish false signatures from true failures. For example, puddles or springs do not usually appear as black as surfacing effluent. Furthermore, the location of the pool coupled with the lack of lush vegetation in the shape of the leaching field may allow a trained observer to distinguish naturally

occuring water from surface outbreaks. Finally, the shape of the object can assist the interpretor since effluent does not usually exhibit the regular (often rectangular) patterns of manmade objects.

Several features can mask the signatures of surfacing effluent.

- o Shadows caused by buildings and trees or slopes can make it difficult to distinguish lush vegetation or pools of effluent in the CIR images.

- o Trees such as deciduous trees in leaf or evergreens can obstruct the view of failing SAS's by blocking the line of sight between the ground and the camera.

- o Uncontrolled Growth of yard vegetation can block the signs of surface breakouts. There may be so much growth that the film is unable to register differences in the lushness of vegetation. However, experience with CIR aerial surveys indicates that very few homeowners allow their lawns to grow completely wild, so the problem is not serious (Evans, Slonecker, personal communication).

A number of factors that might be expected to mask the signatures of surfacing effluent, but do not (Evans, Slonecker, personal communication).

- o Fertilization is not a major problem because homeowners do not normally apply as much nitrogen to their lawns as is provided by septic tank effluent. Also, the excess growth depends on the presence of nitrogen and water -- the soils over the SAS would have moisture and support more lush vegetation than the rest of the yard.

- o Irrigation or sprinkling alone cannot promote growth in the rest of the yard equal to that over the SAS since the irrigating water is usually low in nutrients. Also, sprinkling does not saturate an area as consistently and thoroughly as does ponding effluent.

- o High Groundwater lacks nitrogen so that vegetation will be more lush over the SAS where nitrogen is present than elsewhere. Furthermore, high groundwater increases the likelihood of surface outbreaks.

- o Lawn mowing might be expected to destroy the signs of lush vegetation. However, homeowners are often reluctant to mow soggy areas, so there is commonly a patch of unmowed grass over the ponding SAS which can be identified in the photos. Furthermore, even when mowed, grass over the SAS is denser and healthier looking than the grass in other areas.

3.6 LIMITATIONS ON THE USE OF CIR AERIAL SURVEYS

Septic tank-soil absorption systems can fail in the following ways:

- o sewage backing up into the home

- insufficient treatment below the SAS to protect groundwater from contamination

- surfacing of effluent due to failure of the SAS to accept effluent at the volume applied.

The effectiveness of CIR aerial surveys depends upon the presence of surface manifestations of ponding effluent. Because the first two classes of failure have no effect on the land above the septic system, they cannot be detected with CIR aerial photography. Similarly, CIR aerial surveys will usually fail to detect SAS bypasses to surface disposal in ditches or surface waterways.

Thus, CIR aerial surveys should only be used in instances where surfacing effluent is the problem of concern.

CHAPTER 4

PROCEDURES

4.1 INTRODUCTION

This chapter summarizes the procedures used in CIR aerial surveys. The survey can be divided into five parts:

- o survey preparation
- o image acquisition
- o interpretation
- o ground verificiation
- o report writing.

This chapter briefly analyzes the advantages and disadvantages of the available options and describes the "best practices" for equipment and procedures.

4.2 SURVEY PREPARATION

It is necesary to obtain background information on the area before taking CIR aerial photographs. The background data are used to set up the survey, identify potential flying dates and routes, and improve the accuracy and the speed of interpretation. Often the required background information already will have been collected as part of a 201 facility or areawide planning processes.

- o Climate information is needed to determine the timing of the flight. Flights must be made during the growing season.
- o Soils data should be collected to identify the areas where SAS failures are most likely to occur. This information can be obtained from Soil Conservation Service, soils maps or from local officials. This data is an important adjunct to the interpretation process discussed below, since it can help the interpreter distinguish false from real signatures.

- Housing Use Characteristics are important because overt failures will not be evident in seasonal homes unless the photography occurs during or just after the residents have been in the home.

- System Design Regulations for present and past types of systems normally installed, such as set back requirements, or design and sizing criteria should be obtained from county health personnel. This information helps to predict expected placement of the systems in the yards, and typical signature patterns.

- Maps of Sewered Areas help to distinguish areas where failures are less likely to be found. Failing septic systems can be found in the sewered areas where isolated homes have not been connected to the sewer system (Evans, personal communication).

- Groundwater Depth data is used to identify areas where failures are more or less likely to occur, characteristics of the signatures, and the best time for the flight. Flights should occur when groundwater is at its highest. Data on the groundwater depth and fluctuations can often be obtained from USGS maps.

- Geological Data is important in the absence of good soils maps. Soil information can be obtained from USGS maps or inferred from the area's geological characteristics.

- Topographical Maps are used to design the flight lines. USGS 7.5 or 15 minute quadrangle maps are excellent for this purpose. They also indicate slopes, drainage ways and streams, which is data that helps in the interpretation of the images.

CIR aerial surveyors currently devote from one or two person-days, to over one person-month in this phase of the survey. Our research indicates that the lesser level of effort is sufficient to provide an accurate survey. If the area is very large, collecting and reviewing the background data may require more time. Extensive data collection and analysis appears to be unnecessary for the purposes of identifying surfacing SAS's alone. However, if the CIR aerial survey is an integral part of a study to identify suitable sites for onsite systems, or to design a community wastewater management system, extensive data collection and analysis would be required, but this research should not be attributed to the costs of CIR aerial survey.

4.3 IMAGE ACQUISITION

This section describes the equipment, such as film, cameras, and airplanes, as well as technique used in aerial CIR photography. The discussion of the technique describes the ideal scale, image overlap, season, and weather conditions. This section also discusses film processing.

4.3.1 Aerial Photography Equipment

Film

Many different films can be used for aerial photographic surveys of vegetation. The superiority of CIR film was discussed in Chapter 2. Briefly, black and white, black and white IR, and thermal IR do not provide enough detail to detect ponding effluent, and color film is simply less sensitive to the surface manifestations of ponding systems than CIR.

Color film has some value, however. Distinctions between dead and living vegetation are clearer in color images, and people unfamiliar with CIR film can be confused by the false colors and fail to recognize familiar objects on the ground. For these reasons, some CIR aerial survey firms use both color and CIR film.

The advantages of color photography, do not appear to be worth the added cost. Accurate interpretation requires considerable experience in the field of aerial CIR photography and interpreters with sufficient expertise would not be misled by the false colors. Furthermore, using both color and CIR film can double the cost of image acquistion. In addition to the added cost of the color film and processing (125 feet of 9.5 inch aerial color film costs about $450), the area would have to be flown twice unless the aerial photographer was equipped with two cameras or used an ENVIRO-POD (a panoramic dual camera system discussed below).

There are only three varieties of CIR film, all made by Kodak. Of these only Aerochrome 2443 can be used at the low altitudes and with the single engine airplanes commonly used by aerial photography firms. Aerochrome 2443 has a resolution of 63 lines/mm in high contrast, and 32 lines/mm in low contrast (Eastman Kodak, 1976a). The film is available in 35 mm, 70 mm, and 9.5 inch widths. The 70 mm is used with the ENVIRO-POD while the 9.5 inch film is used in standard photogrammetric mapping cameras. Survey costs are higher when the smaller film sizes are used. This relationship is discussed further in Chapter 6.

The other two film types are Aerochrome Infrared Film SO-127 and SO-131. Although their cost is comparable to the price of low altitude film and they have extremely high resolution (160 lines/mm), they are meant for high altitude, stable platform flight. Any attempt to use these films below 20,000 feet results in a blurred picture because of the ground motion relative to the film (Otto, personal communication). Thus, they could never be used by local aerial photographers who typically fly at 2000 feet. These films are most commonly used for high altitude government reconnaissance.

Cameras

Currently two different types of cameras are routinely used to locate surfacing septic tank effluent:

- EPA's ENVIRO-POD
- standard photogrammetric mapping cameras with three or six inch lenses.

ENVIRO-POD is a portable unit consisting of two connected panoramic KA-85A cameras that can be easily mounted on the outside of any Cessna series 172 or 182 aircraft. The forward unit is oriented to photograph the nadir (the midpoint of the line of flight directly below the camera) and provides a vertical image. The aft camera, which points 45 degrees in front of the nadir, takes an oblique shot. The cameras have an 80 mm lens. Currently there are 20 such systems with at least one in each EPA regional office. It is also commercially available.

The ENVIRO-POD has several advantages over conventional photogrammatic mapping cameras:

- The images are clearer because of camera lens quality (EPA, 1978)
- The camera can be used in areas where there is no professional aerial photographer because the surveyor can bring the camera to the survey site and attach it to a rental aircraft.
- The two cameras can be used simultaneously to take color and CIR images
- The oblique camera provides images of a familiar view of the terrain that are more easily interpreted by the layman.

The ENVIRO-POD has the following disadvantages.

- Panoramic cameras only take a vertical shot at the center of the picture (the nadir). The obliqueness of photography (and therefore the scale) increases with distance from the line of flight of the airplane. This makes interpretation difficult because as scale increases detail decreases. Furthermore, as obliqueness increases objects on the ground will increasingly obscure the view of what lies behind them. However, at the scale used for septic tank screening, this is not a major problem (Evans, personal communication).
- Because the ENVIRO-POD requires 70 mm instead of 9.5 inch film, the costs of image acquisition and interpretation are higher. This issue is discussed in greater detail in Chapter 6.
- The cameras only hold enough film to photograph a 22 square mile area (at a scale of 1:8000). Because the cameras are on the fuselage, the camera cannot be reloaded in flight.

Hand-held 35 mm cameras have also been used in CIR aerial surveys. Like the ENVIRO-POD, they increase the cost of image acquisition considerably since film, development, and flying costs are substantially higher due to the smaller area covered in each photograph. Also, it is not possible to obtain stereo images with hand-held 35 mm cameras. More sophisticated camera systems that could be used are more costly, not generally available, and require more sophisticated airplanes and photographic procedures.

Standard aerial photogrammetric mapping cameras are the preferred camera system for CIR aerial surveys for the following reasons.

- o They are the least costly to operate because of image size (see Chapter 6).

- o They have a greater range. At a scale of 1:8000, one roll of film covers 50 square miles using standard aerial photographic mapping procedures (discussed in Section 4.3.2). The range is even greater because film can be reloaded inflight.

- o They are not panoramic cameras so that scale and obliqueness does not increase with distance from the line of flight.

The ENVIRO-POD might be preferable for a small survey area with no aerial photographer within a reasonable flying distance.

Filters

Filters are always used in CIR photography to screen out the blue wavelengths. Because all of the film layers are sensitive to blue wavelengths, CIR film will lose sensitivity in the absence of the filter (Eastman Kodak, 1977). Kodak recommends a Wratten 12 for distinguishing foliage, but the Wratten 8, 12, 15, and 21 filters can be used depending upon the purposes of the photograph. Different filters will emphasize different wavelengths. CIR aerial surveyors have reached the conclusion that the commonly used Wratten 12 filter provides the best contrast for the purposes of detecting surfacing effluent (Slonecker, Evans, personal communication).

Airplanes

The choice of airplane is up to the photographer. Single engine planes offer the advantages of slower flying speeds (which allows the film to operate at a slower speed and increases its sensitivity), lower altitudes, lower cost, and greater maneuverability (Poulton, 1975). Twin-engine planes are more stable and have a greater flying range. Using high-altitude, high-speed planes would not be cost-effective for CIR aerial surveys.

Cessna series 172 and 182 are the only planes licensed by the Federal Aviation Administration (FAA) for use with the ENVIRO-POD. The system was designed for these single engine planes which were selected on the basis of availability and low cost.

4.3.2 Aerial Photographic Procedures

There are a number of issues regarding the operation of the cameras:

- o scale

- o altitude

- o camera angle
- o image overlap
- o camera settings
- o flying procedure.

Many of these factors are interrelated because of the geometry of aerial photography and standard procedures have been developed by the aerial photography profession.

Scale and Altitude

Scale is the ratio of distance on the film to distance on the ground. For example, at a 1:8000 scale, 1 inch on the photograph will equal 8000 inches on the ground.

Scale and altitude are related by the formula:

scale = F/H

where:

F is the focal length of the lens
H is the altitude.

At 4000 feet, a six-inch (0.5-foot) lens would give a 1:8000 scale. The choice of altitude depends upon the desired scale and the lens size. The choice of scale depends upon a number of factors (Crouch, unpublished masters thesis):

- o the FAA minimum flying altitudes
- o the degree of detail desired in each picture
- o the ground resolution of the film
- o and costs of photography and image interpretation.

FAA has established 2000 feet as the minimum legal flying altitude over developed areas. Exhibit 4-1 presents the maximum possible scales using standard lenses.

As the scale increases, for example from 1:8000 to 1:4000, costs increase because more images must be taken of a given area. The relationship of scale to the area covered in an image is as follows. The reciprocal of the formula relates numbers of photographs needed to cover a given sized area.

$$Ag = L_i W_i / \text{scale}^2$$

EXHIBIT 4-1

MAXIMUM LEGAL SCALES BY LENS FOCAL LENGTH

FOCAL LENGTH	SCALE @ 2000 ft. Altitude
2.17" (55mm)	1:11111
3"	1:8000
5.31" (135mm)	1:4516
6"	1:4000

where:

Ag is the ground area covered by image
L_i is the length of the image
W_i is the width of the image.

Appendix B presents the formula for calculating production.

If scale decreases by a factor of 2 (e.g., goes from 1:4000 to 1:8000) the area covered in the photography will increase by a factor of 4, and the number of photographs per square mile will decrease by a factor of 4. Exhibit 4-2 presents the number of images required to cover a square mile at different scales and different levels of image overlap. The film used in the analysis is 9.5 inch, but results are similar for other films.

Selecting a photographic scale involves a tradeoff between costs and the amount of detail that can be seen in images. Since flying time, the amount of film, and the number of images that must be interpreted decrease with decreasing scale, from a cost standpoint it is desirable to fly at as small a scale as possible. However, the interpretability of the images increase with scale because the film is able to register more variations in the landscape.

The sensitivity, or ground resolution, of the film depends on the differences in energy reaching the lens between the object and background, the quality of the lens, and the spectral sensitivity of the film emulsion (Estes and Simonett, 1975). Sensitivity is measured in lines per millimeter (LPM): the number of parallel lines that can be distinguished in a millimeter of image. The greater the LPM, the greater the sensitivity of the film (Estes and Simonett, 1975).

Aerochrome 2443 has a sensitivity of 63 LPM for conditions of high test to object contrast and 32 LPM under low contrast (Eastman Kodak, 1976a). Under low contrast conditions at a 1:8000 scale, an interpreter can distinguish objects of 242 square inches or approximately two square feet. Under conditons of high contrast, it would be possible to resolve an area of approximately one-half square foot in size.

See Appendix B for the derivation of this formula.

The photographic characteristics of the subject area and the exposure conditions can also affect the resolution. As contrast increases, so do LPM. In addition, the ability to resolve an object depends upon:

- its brightness
- its length to width ratio
- the regularity of its size or shape
- the number of objects comprising the pattern to be resolved

EXHIBIT 4-2

IMAGES/SQ. MI. (ASSUMING 9.5" X 9.5" MAPPING CAMERA)*

Scale	No Overlap	30% Sidelap For Coverage	30% Sidelap and 60% Overlap Stereoscopic Viewing
1:2000	12.3	19.7	31.5
1:3000	5.5	8.8	14.1
1:4000	3.1	5.0	7.9
1:5000	2.0	3.2	5.1
1:6000	1.4	2.2	3.6
1:7000	1.0	1.6	2.6
1:8000	0.8	1.2	2.0
1:9000	0.6	1.0	1.6
1:10000	0.5	0.8	1.3

*Actual image size is 9".

See Exhibit B-1.

- o the uniformity and extent of the background
- o image motion to film during the exposure
- o atmospheric haze.

Therefore, it may be possible to detect smaller objects than that defined by film sensitivity, if, for example, the image is very long, or has a high contrast (Estes and Simonett, 1975).

At a scale of 1:8000 it should be possible under good conditions to detect surfacing effluent covering about a square foot and recognize dead vegetation characteristic of ponding systems if it covers areas of three to four square feet. Lush vegetation is detectable in small amounts because of contrast and its usually long, narrow shape. These theoretical calculations are born out in practice (Slonecker, personal communication).

According to the most experienced practitioners, scales of 1:8000 offer the best compromise between sensitivity and cost (Slonecker, Evans, Johnson, personal communication). Crouch tested both 1:8000 and 1:6000 and found the resulting images equally interpretable. Scales ranging from 1:4000 to 1:10,000 were tested in early EPA experiments (Wolle, personal communication). These indicated that interpretation became increasingly difficult at scales smaller than 1:10,000. The tests also showed that the ease of identification of failing systems did not improve at scales greater than 1:8000. Crisp (personal communication) confirmed these findings with his own tests. Flying the same area at 1000 ft (1:4000 scale), 2000 ft (1:8000 scale), and 4000 ft (1:16000 scale) he found that the failure signatures were barely identifiable at the highest altitude, even when he knew where they were located. Haze also increased the difficulties of interpretation at this altitude. Crisp determined that 1:8000 afforded him a good view of the systems and that there was no improvement at 1:4000.

Camera Angle, Image Overlap, Camera Settings, and Flight Procedure

Most CIR aerial survey practitioners use standard photogrammetric mapping techniques. These procedures have been established over the years by professional aerial photographers. Camera angle, image overlap, camera operation, and flying procedures are all well researched. Although practitioners have attempted to use other methods, these result in increased flying time and film costs. Any experienced aerial photographer familiar with CIR film could complete a CIR aerial survey without special training.

For standard mapping cameras, the camera angle of choice is vertical. The ENVIRO-POD uses a 45^{o} camera angle for the panoramic screening because, according to its designers, this gives the best panoramic view of the scene.

The image overlap serves two functions. It allows the interpreter to achieve a stereoscopic affect because it provides two images at slightly different angles. Image overlap also minimizes obliqueness. Even with a vertical camera, the edges of the photograph will be more oblique than the

center. The greater the image overlap, the less loss of accuracy because of the surveyed ground area being obscured by houses, trees, and other tall objects. However, expense increases with image overlap: more film must be exposed, the plane must traverse a greater number of flight lines, and more images must be interpreted.

Standard photographic mapping technique involves overlapping images 30^{o} on each side (Estes and Simonett, 1975). Standard technique also involves overlapping the images 60% in the forward direction to allow for stereoscopic viewing (Estes and Simmonett, 1975). Although stereoscopic viewing increases film requirements by 1.6 times, it does not add to flying time, so the extra cost is not significant. The benefits of improved interpretation accuracy and image resolution are well documented (Estes and Simonett, 1975). The advantages of using stereoscopy in CIR aerial surveys are explained in greater detail in Section 4.4.

The camera settings are determined by the film, the altitude, the sun angle, and haziness. These are standard and any aerial photographer familiar with the film would be able to determine the proper settings (Eastman Kodak, 1976b). The Kodak Aerial Exposure Computer (Publication Number R-10) is a reference document that can be used to determine camera settings. It consists of a latitude zone map, solar altitude tables, and two circular slide rule calculators. One of these "dial computers" relates ground speed and altitude to image velocity, with different lens focal lengths, altitudes, and miles per hour. The other dial computer calculates the proper exposure setting as a function of solar altitude, haze, aerial film speed, and flight altitude. Using them, a photographer can determine the correct camera settings for any conditions of flight. CIR film is very sensitive so the exposure and timing must be set carefully (Keefer, personal communication).

While aerial cameras can be operated manually, they are almost universally automatic. The film advances at the rate required for the flight speed, image overlap, and scale of photography. The flight is flown along predetermined flight lines, drawn with 10% leeway either way so that ground objects of interest can be included in a particular series (Estes and Simonett, 1975). Generally United States Geological Service maps are used to plot the flight lines, using geological or manmade features to demark boundaries (Evans, Slonecker, Crouch, personal communication).

Another photographic approach is to use a hand-held 35 mm camera, and position the plane to get the most revealing shot of each neighborhood. This is a much more time-consuming procedure: one practitioner estimates that it takes an hour and a half to photograph a 2 mile by 3/4-mile area (Morlock, personal communication). Assuming a flight speed of 100 mph, it would take roughly ten minutes to photograph the same area at the same scale using standard mapping procedures. The time required to overfly an area depends on the width and length of the survey area, flight speed, scale, and size of film. The survey area width, scale, and film size determine the number of passes required, and survey area length and flight speed determine the length of time required for each pass. See Chapter 6 for the flight time formula.

4.3.3 Flight Schedule

Experience with the technique indicates that time of day and season affect accuracy and the amount of information obtained. The following factors should be considered when scheduling the photography:

- o season
- o depth to groundwater
- o system usage
- o time of day
- o weather conditions.

Season

In most parts of the country, flights should be conducted in the early spring or late fall--the only times of year when the following conditions are met.

- o Snow must be off the ground so that the failure signatures are not obscured.
- o Trees should be leafless so that the line of sight between the airplane and the ground is not blocked. Surveys of several lakes in North Dakota and in Seattle, Washington, conducted when the trees were in leaf, missed many systems (Slonecker, Sriebers, and Fewless, personal communication). In neighborhoods with few trees this is not a major concern.
- o Lawns should not be totally dormant so that the differences in the vegetation are visible. Although overtly failing systems can be seen when the lawn is dormant, the accuracy and power of the survey suffers. Many clues used to differentiate false signatures from actual signatures are unavailable. Furthermore, it is impossible to locate some seasonal failures if the lawns are dormant.

The growing season begins shortly after the last frost of winter and ends after the first frost of fall. The warm, nutrient and moisture-laden surfacing effluent extends the growing season somewhat in the immediate area. Thus, vegetation over failing SAS's start growing earlier than other vegetation and stays green until somewhat later. Experience with the technique indicates that differences in the vegetation are detectable from slightly before the beginning of the formal growing season, throughout the spring and summer, until slightly after the first frost (Evans, Slonecker, Johnson, personal communication). There is no need to select a period when the lawn is dormant in every place except over the SAS.

Spring is preferable to late Fall in the northern half of the United States because north of 40^{o} latitude, the solar altitude never exceeds 45^{o} after October 5 as opposed to at least 65^{o} before April 22 and

August 20. The solar angle or altitude is the angle made by a line to the sun from a plane and the ground. It is important because it affects the lengths of the shadows. Shadows obscure the signatures of surfacing effluent, and are longer when solar altitude is lower. The length of a shadow equals:

S is H/tan a

where:

S is length of the shadow
H is height of the object
a is solar altitude

The shadow of a 40-foot tall house with a leaching field located twenty-five feet north of its side (or 40 feet from the peak of the roof), would first reach the SAS when the sun's altitude equalled 45 degrees. The shadow would continue to cover more as the solar altitude decreased. Solar altitude decreases as latitude increases. Thus, shadows become an increasingly serious problem the further north the CIR aerial survey site.

Location of the Water Table

Flights should occur when the groundwater level is at its maximum because surfacing is likely to be most severe under these conditions. This is a worst case approach: if systems perform under these extreme conditions, they probably will not fail at other times. Similarly the seasonal failures will be most easily identified. High groundwater may increase the number of natural springs and pools which may be mistaken for surface outbreaks, but experienced surveyors state they have not been affected by this problem (Slonecker, Evans, personal communication). However, in early experiments, inexperienced interpreters had difficulty distinguishing between yard springs and failing SAS's (Slonecker, Pavey, personal communication).

System Use

Flights should be scheduled when the systems are in use. Use also affects the likelihood of failure: the greater the use, the greater the chance of SAS overload. This affects the choice of the season and particular day of flight. For example, seasonal homes should be evaluated when failures are likely to occur. This creates a quandrary for wooded areas with many summer cottages: the best flying time is Spring and Fall, yet such areas have low occupancy rates at this time. Weekends are usually preferable to weekdays in areas with a high proportion of vacation homes.

Time of Day

In order to minimize the impact of shadows and maximize insolation (the amount of sunlight reaching the earth), flights should occur when the solar altitude is at its maximum. Because solar altitude reaches its maximum at solar noon, and decreases with hours away from noon, it is desirable to fly as close to solar noon as possible.

Weather Conditions

Because puddles of rainwater can be mistaken for surface breakouts, photography should not be attempted immediately after a storm. The exact amount of delay required depends upon the amount of rain and the rate at which it leaves the surface. Surveyors generally wait two or three days after a storm (Evans, Slonecker, personal communication).

Because water will absorb IR radiation, flying on foggy or particularly humid days is inadvisable (Eastman Kodak, 1977). Photography should be done on clear days. Overcast, partly cloudy, and partly sunny conditions are all undesireable because the amount of near infrared radiation a plant reflects depends upon the amount of sunlight it receives. With less insolation there is less reflection and the images appear darker. Darker images have less contrast and are harder to interpret (Estes and Simonett, 1975). Even patchy clouds can create problems because some images will be darker than others. Unlike color film, CIR film can penetrate haze.

4.3.4 Film Handling and Processing

CIR film must be kept frozen until it is loaded in the camera. Film can be processed in-house or at several laboratories around the country. Eastman Kodak's publication M-29, Kodak Data for Aerial Photography, 1976, explains the various methods for processing the film. Because of cost and ease of interpretation, color transparencies are preferable to prints.

4.4 INTERPRETATION

4.4.1 Interpretation Equipment

The equipment needed for interpretation consists of a light table and a stereoscope with magnification. The light table should be illuminated to about 50 footcandles, there should be a minimal amount of glare, and the source of light should be appropriate for the film and of a full spectrum that will result in true colors (Estes and Simonett, 1975). Mercury vapor, sodium vapor, and standard fluorescent lights should not be used (Estes and Simmonet, 1975). See Smith and Anson (1968) for a detailed discussion of proper illumination practices.

Several varieties of stereoscopes are available. Standard pocket stereoscopes which provide magnification of up to 4 times are most commonly used (Evans, Slonecker, personal communication). Other varieties such as mirror or zoom stereoscopes can give better resolution but are more expensive.

4.4.2 Interpretation Procedures

The color transparencies are placed on a light table, and viewed with the assistance of a pocket stereoscope and magnifying optics. Two succesive transparencies are positioned next to each other on the light table to permit three-dimensional viewing. Three-dimensional viewing helps the analyst to:

- identify flat or gently sloping terrain most likely to have SAS
- recognize plumes of vegetation indicative of lateral movement of effluent on the surface since surface outbreaks will flow downhill
- better discriminate yard objects or characteristics that could mimic the signatures -- for example, slopes will be shadowed, appear dark, and may look like surfacing effluent (Evans, Slonecker, Filbey, personal communication).

Interpreters examine the images for signs of ponding effluent. However, signatures change with soil types, groundwater depths, and system design; thus, practitioners have developed keys to help them analyze the images in light of these variations. RSC and EPIC verify their interpretation of the images by ground inspection of all or a portion, respectively, of the systems they suspect are failing. The results of this process, coupled with what is known about the soils, system designs, and groundwater in the area are applied to future CIR aerial surveys. Occasionally, they reinterpret an entire set of images in light of the information they collected during the ground verification (Evans, Slonecker, personal communication).

Interpretation is a time-consuming process. One practitioner estimates that he can analyze from 400 to 500 lots per day, depending on the characteristics of the area (Evans, personal communication). Eye strain becomes a problem if interpreters try to review more than 500 lots per day. EPIC estimates that it takes roughly eight hours to review a USGS map quadrangle (55 square mile) photographed on 9.5 inch film, and 12 to 14 hours per quadrangle when the ENVIRO-POD is used (Crook, personal communication). The extra time required is a function of the additional images that must be handled when the ENVIRO-POD is used.

A number of factors in addition to those issues discussed under flight scheduling can affect the difficulty of interpretation.

- Type of system affects the signature. Systems with small areas such as seepage pits, and trench systems with unusual layouts will have small or unusual signatures. Systems may also be missed due to their unconventional locations (Slonecker, personal communication).
- Small lots are difficult to interpret because the congestion, clutter, and shadows in the images make it difficult to distinguish the signs of surfacing effluent from other yard features (Evans personal communication).
- Topography such as small hills and valleys may obscure systems (Evans, personal communication).
- Interpreter Experience affects the numbers of failing systems (false negatives) missed and the number of properly operating systems mistaken for failures (false positives).

4.5 GROUND VERIFICATION

Once the analysis is complete, it is essential to verify the findings. All or a portion of the systems identified as failures must be examined by someone who is familiar with the ground manifestations of surfacing effluent. Ground verification is necessary because:

- ground objects may be mistaken for failures
- the key may be not suited to local soils and system designs.

EPIC visits roughly 10% of the sites identified as overt or seasonal failures in the survey. Those sites are selected to be representative of different soil types, varieties of systems, physical characteristics of the signatures, and groundwater depths (Slonecker, personal communication). Their extensive analysis of the soils, geology and system design prior to the survey makes it possible to inspect fewer systems. This approach provides an estimate of the proportion of failures in a community, but does not provide a hard number. RSC inspects every site that has signs of surface outbreaks (Evans, personal communication). Houses showing signs of seasonal stress clustered near houses that had failure signatures should also be checked (Evans, Slonecker, personal communication).

Generally two people should be involved in the survey -- someone familiar with the survey results, and a member of the local health department. Local officials lend credibility to the survey, are familiar with the area, and generally have legal authority to inspect the systems (Evans, Slonecker, personal communication). RSC assumes that one person can verify about 40 signatures a day (Evans, personal communication). EPIC calculates that ground verification takes from 2 days to a week, depending on the size of the area surveyed (Crook, personal communication).

The verification should occur as soon after the aerial survey as possible (Evans, Slonecker, personal communication). Conditions will change with time: the longer the delay between the photography and the ground survey, the greater the divergence in the status of the SAS's. For example, systems that had photographic signatures of surface outbreaks may no longer be failing when they are inspected. While the signs of past failure will still be apparent (unless the delay is over several months), the survey may loose credibility. Ideally the ground verification should be performed as soon as possible after the photographs have been taken. It is possible to wait through a season -- from late fall to early spring, for example, without damaging the accuracy of the results too severely (Evans, Slonecker, personal communication).

4.6 REPORT WRITING

Report writing consists of preparing the survey results in a useful form. Generally the reports consist of maps identifying overt and seasonal failures and text describing the survey procedure, results, and limitations of the data. Optional items include pictures of failing systems and

extensive background data on the soils, system design, and groundwater table levels collected during survey preparation.

The amount of information contained depends upon the intended use of surveys. Depending on the size of the area and the amount of information included, report preparation takes from two days to a week (Evans, Crook, personal communication).

CHAPTER FIVE

EXPERIENCE WITH CIR AERIAL SURVEYS

5.1 INTRODUCTION

Personnel involved with 35 aerial surveys were interviewed. Much of the information from these interviews is anecdotal. Exhibit 5-1 lists the surveys reviewed, and summarizes the available data on cost, size, failure rates, false positives, and false negatives. In many instances the respondents estimated the data. Although the data are sketchy, EPIC's and RSC's costs ranged from $0.79/house to $4.00/house, in survey areas containing 1000-8000 houses, for surveys ranging from 1.5 to 100 square miles.

5.2 ACCURACY

There are two components to the accuracy of CIR aerial surveys, the number of normal systems mistaken for failures, and the number of failing systems missed by the survey. The false positive rate is the ratio of systems that appeared to be failing in the images, but which proved to be operating properly upon inspection to the total number of systems interpreted as failures.

The false negative rate is the ratio of failures missed to total failures. The question of survey accuracy is confused somewhat by differences of opinion about what constitutes failing SAS's. As discussed in Chapter 3, lush vegetation in and of itself is not indicative of a failing SAS, although it may indicate that the system could fail in the future. Only those SAS's showing signs of present or past overt outbreaks of effluent should be termed failures.

However, the interpretation of the significance of excess vegetation over the systems was a matter of dispute in some instances. In Lewes and Rehoboth Beach, Delaware for example, the systems are quite shallow, and the soil is sandy. EPIC's ground validation confirmed the presence of excess vegetation or surfacing effluent in 75% of the yards that looked suspicious in the photographs, so they derived a false positive rate of 25% (Slonecker, personal communication). However state and local officials thought that only about 10% of the systems identified by EPIC actually showed signs of past or present surfacing effluent (Esposito, Garris, personal communication). This results in a false positive rate of 92%.

Exhibit 5-1

EXPERIENCE WITH AOSS

	Surveyor	Houses	Cost/ House	Sq. Mi.	Suspected Failures (Total)	Percent False Positive	Number Failures Missed
Bellville, Ind.	Pavey	280	$10.34	2.8	--		
Franklin Village, MI	RSC	1,000	$3.50	1.5	121	82%	a few
East Goshen, PA	EPIC	5,000		2.5	--	--	
Blount County, TN	EPIC	15,750	$1.24	7.5	1,704	good	10%
Spearfish, SD	EPIC	3,000	$3.50	30	56	21%	1
Baileyville,					150	10%	neg.
Luttrell, &	EPIC	580	--	13.3	150	27%	neg.
Surgoinsville, TN					75	70%	several
Kent and Sussex, DEL, Coastal					189	25%	neg.
&	RSC	2,500	$4.00	20			
Inland					86	41%	neg.
Frankford					97	65%	neg.
&	RSC	400	$5.00	2.25			
Dagsboro, DEL					23	22%	neg.
Lewes & Rehoboth Beach, DEL	EPIC	--	$2,600*	--	475	6% EPIC	several
						84% (DEL)	
Orlando, FL	EPIC	--			280	--	--
King County, WA	EPIC	--	--	150	--	BAD	many
Fargo					159	no surface	neg.
&	FMSL	--	--	--	--	failures	
several lakes, ND					12	--	95%

Exhibit 5-1 (continued)

EXPERIENCE WITH AOSS

	Surveyor	Houses	Cost/ House	Sq. Mi.	Suspected Failures (Total)	Percent False Positive	Number Failures Missed
Horsham, Warminster, and Warrington, PA	EPIC	--	$10,000*	400	--	--	--
Chalfont-New Britian & Buckingham Twp, PA	EPIC	6,000 2,000	$1.37	100	812 398	5% 5%	neg. neg.
Jefferson County, KY	EPIC	7,000	$.79	45		20%	neg.
Bushkill & Plainfield, PA	EPIC	6,200	$1.61	56	843	10-40%	neg.
Shawnee County, KAN	EPIC	--	$7,300*	17	60	66%	neg.
Rapid City, SD	EMSL	--	$1,000*	65	50	50%	several
Marion County, KAN	Crisp	200	$1.25	.8	245	0%	0
Stanley County, NC	EPIC	1,356	--	--	200	35%	neg.
Louisville, KY	EPIC		--	--	0	--	--
Nettle Lake		--		--	0	--	--
Steuben, IND		3,500		38	45	81%	neg.
Cook & Pickerell Lakes, MI	EPIC	212		3.75	34	76%	neg.
Otter Tail Lake, MN		1,440		23	3	33%	neg.
Crystal Lake, MI		550		15.3	100	71%	neg.
Green and Nest Lakes, MN		5,400		1	475	96%	neg.
Total		11,052	$2.84	81			--
Lake Geneva, WI	EPIC	--	--	--		--	--
Ann Arundel County, MD	EPIC	--	--	--	--	--	--

*Total Survey Cost neg. = negligible

Individuals familiar with the Rapid City, South Dakota survey had similar reactions. EMSL said that all of the systems that showed signs of excess vegetation were suspicious. However some respondents questioned that statement, since their own records and ground surveys revealed that very few of the systems had ever failed (Hovey, Markly, Strub, personal communication). One North Dakota state official had a similar question about the Fargo, N.D. survey, although local officials believed that the systems identified by EMSL would probably fail in a wetter year (Fewless, personal communication).

5.2.1 False Positives

Because all or a portion of suspected failures are routinely verified through ground inspections, there was good information on the false positive rate. The rate was generally quite high -- from 10% to 93% -- although most hovered around the 50% range.

The false positives stemmed from yard objects, recent rainfall, lawn destruction, backyard springs, or excess vegetation that was not connected with problem systems. Recent rainfall was a significant problem. One survey in Seattle, Washington (Evans, Slonecker, personal communication) was completed just after a rainfall. The false positive was unacceptably high because pooled rainwater was frequently mistaken for surfacing effluent (Sriebers, Slonecker, personal communication).

Because the overall suspected failure rates were low -- from 2-20% of the houses contained in the survey, the high false positives did not add appreciably to the cost of ground verification. However, the rate is high enough to make ground verification an essential part of CIR aerial surveys. The opinion of local officials on significance of excess vegetation adds to the importance of ground verification.

5.2.2 False Negatives

Information on the false negative rate is quite subjective since the clients and surveyors did not inspect yards that appeared normal in the photography. Despite the lack of concrete data, the rate is believed to be quite low in all but a few instances. In most cases, respondents said that in the time since the CIR aerial survey had been completed, they had found no failures other than those identified in the survey. However, the respondents had made no concerted attempt to find additional failures and had little reason to do so.

In several areas, ground surveys, questionaires, or "windshield surveys" were conducted in addition to the CIR aerial survey, or local health agency files were reviewed. These additional studies occasionally revealed failures that had been missed, but the number was very low (1-3) and did not, in the client's view, affect the value of the survey (Evans, Swem, Crisp, personal communication). One survey that identified 21 failures missed two (Wilson, personal communication). One was a direct discharge to the lake which could not have been identified through a CIR aerial survey. The other had been blocked by trees.

The false negatives were unacceptable in several of the surveys.

- o Lewes and Rehoboth Beach, Delaware The surveyor missed several failures identified through a mail survey (Esposito, personal communication). Similarly, many blatantly failing systems were missed, and many properly operating systems were termed failures.

- o King County, Washington This survey was done when the trees were in leaf, so many failures were missed (Sriebers, Slonecker, personal communication).

- o North Dakota Lakes in this survey missed 20 out of 21 yards with surfacing effluent (Fewless, Altenbrand, personal communication).

- o Rapid City, South Dakota This survey also missed several failing systems which were very obvious on ground visits (Strub, personal communication). Several narrow river valleys were surveyed which made interpretation difficult.

While false negatives usually arose because the systems were obscured in some way, there were a few other reasons. Some of the false negatives found in North and South Dakota could be attributed to tree cover, but respondents said that many others were in open areas (Fewless, Altenbrand, personal communication). The inaccuracies in the surveys in the Dakotas may result from survey technique. The surveyors initially developed an interpretaton key for different soil types which they validated only through conversations with local health officials rather than ground inspections (Johnson, personal communication). Since the surveyors do no verification of their surveys, they have never refined the key. The accuracy of the surveys was poor in one town of a three-town survey and excellent in the other two towns. The only difference among these towns was the interpreter. Inexperienced personnel interpreted the town with the poor results.

5.3 USEFULNESS

CIR aerial surveys were conducted for one of three reasons:

- o to evaluate the need for centralized treatment, either as part of the alternatives analysis in Step 1 facility planning in the Construction Grants process or to show evidence of need under existing EPA guidelines

- o to evaluate the need for a more rigorous onsite system management program

- o or to experiment with the use of aerial photography to identify failing SAS's.

All but three of the clients interviewed said that the technique answered their questions and was the most effective method for doing so. One of the most important benefits of the technique was that it convinced local politicians and planners of the real magnitude of the system problems in an uncontroversial way.

Another important advantage of CIR aerial surveys is their low cost. Those who liked aerial surveys frequently said that obtaining the same amount of information in any other way would have been much more expensive. Esposito (personal communication) solicited bids for characterizing the status of septic systems throughout Delaware, and the bid of the one contractor who proposed aerial surveys was far lower than any other. Pavey (personal communication) estimated that conventional ground surveys cost $10/house, and Grayson (personal communication) estimated that it would have taken ten analysts two weeks to survey the 1,356 houses in Stanley County, NC. At $100/person day the total cost would have been $10,000. Although mailed questionaires might be less expensive, Swem (personal communication) claims that the response rate for mail surveys is only about 50% and Schultz (personal communication) indicated that the response rate tends to be lowest in areas with the highest failure rates. Windshield surveys, although inexpensive, have limited effectiveness because onsite systems are frequently in the back of houses (Krantsmeyer, personal communication).

One respondent who did not believe that the technique was that efficient, used it on a very small area of 1.5 sq mi, with 1,000 houses (Swem, personal communication). He also had commissioned ground surveys and questionaires to fully characterize all problems with septic systems, including sewage backing up into the house, and groundwater pollution. He felt that the aerial survey was redundant. However, it did identify 8 failures (out of a total of 121) that had not been located through any other survey technique.

Altenbernd (personal communication) believes that, in sparsely populated areas like South Dakota, ground surveys are not much more expensive but much more informative than aerial surveys, since he did not believe that excess vegetation can be taken as a sign of failure. He and other officials in the Dakotas were also concerned about the numbers of failures missed--particularly around lakes. Two other respondents said that the same amount of information could be obtained more cheaply from soils maps (Markly, Strailey, personal communication). However both felt that the technique was an effective way to characterize an area.

Strailey (personal communication) suggested that the most effective way to identify failures would be to present local sanitarians, septic tank pumpers and installers, and soils experts with maps of the area and ask them to draw rings around the places they would expect septic tanks to fail. However, he believes that this technique would not be as convincing to local politicians and planners as the aerial photographs. He claims that the political benefits of aerial surveys are sufficient to make it worthwhile.

There was only one attempt to use aerial surveys for enforcement -- Ann Arundel County, Maryland. This was a failure, because ground vegetation obscured many systems and because the survey was looking for direct discharges into surface waters. Other respondents felt that it would be politically unacceptable to use air surveys in that way. People would object to the notion of a "spy in the sky" and many properly operating systems could be mistaken as failures in the interpretation. The legal issues here are also complex. Given EPA's past litigation and enforcement experience in aerial surveys of major polluting sources, such evidence could easily be ruled inadmissable as a violation of privacy.

Almost all respondents emphasized that aerial photographs are a screening tool and that ground verification is essential to absolutely identify which systems are failing. According to the people contacted, the major value was to drastically decrease the number of lots that had to be inspected for failing systems, and also decrease the amount of time needed to inspect each house. It also gave local officials the justification to inspect particular houses.

Chapter 6

COSTS

The cost of CIR aerial surveys depend on the expense of:

- o survey preparation
- o image acquisition
- o image interpretation
- o ground verification
- o report writing.

These costs depend in turn on labour, material, and equipment prices. A methodology for estimating costs is presented below.

6.1 SURVEY PREPARATION

As discussed in Section 4.2 survey preparation involves collecting and analyzing the background material necessary to plan and run the CIR aerial survey. It is a labour intensive task; its cost depends upon the amount of information collected. At a minimum it takes one to two person days. Somewhat more time may be required for a very large survey area (over 40 square miles), or if the information collected is also used for other parts of the facility planning process.

In some instances it may be difficult to separate the costs of CIR survey preparation from other planning activities. For example, EPIC spends about a person month in this phase of the survey, however, they provide an extensive soils analysis in addition to an estimation of the rate of SAS system failure, and use this information to assess whether systems are actually failing rather than verifying through ground inspection every suspected failure.

Survey Preparation costs equal:

Hours of labour X hourly rate X (1+ overhead rate)

Hourly and overhead rates will vary with the firm used for the survey. For the purposes of this analysis $12.00 per hour and an overhead rate of 100% will be used. Using the two day figure, survey preparation would cost $384. Using the one month figure (20 days), survey preparation would cost $3840.

6.2 IMAGE ACQUISITION

Image acquisition costs depend on the prices of film and development, the hourly costs of the aerial photographer, airplane operation, and pilot, and the length of time it takes to complete the survey. The time required to survey an area is a function of image overlap, scale, camera, flight speed, distance between the survey area and the airport, and survey area shape and size. If CIR aerial surveyors travel to the site and photograph themselves rather than relying on local aerial photographers to obtain the CIR images, travel expenses (transportation, per diem expenses, and time) must also be factored into the costs of image acquisition.

6.2.1 Film and Processing Costs

Film and processing costs depend on the per image cost of film and processing, and on the number of images required to photograph the survey area. Both of these factors vary with the film size and by extension, camera used. In addition, the number of images depends on survey area size, scale of photography, and photographic technique.

Exhibit 6-1 shows the image size for different films and number of images needed to photograph a square mile as a function of scale, camera and film size, and photographic technique. As discussed in Section 4.3, the number of images required to fully photograph a given sized area varies with the square of the scale. As scale increases by a factor of two, the number of photographs increases by 4. For example, when scale increases from 1:8000 to 1:4000 and the ENVIRO-POD is used, the number of images required to photograph a square mile goes from 6 to 24.

In addition, the larger the film, the fewer the images needed to cover an area. At a scale of 1:8000 50, 6, and 1 images respectively are required to photograph a square mile with a 35 mm camera, an ENVIRO-POD and a standard mapping camera. Finally, to insure complete coverage, images are usually overlapped 30% on each side. This increases the number of images per square mile by 1.6. Stereoscopy involves overlapping the images 60% in the forward direction and increases by an additional 1.6 the number of images required.

The number of images required also depends on survey area size. Obviously, the larger the area, the greater the number of images required. The number can be calculated roughly by multiplying the square miles of area to be surveyed by the number of images per square mile at the scale, and using the camera and photographic technique taken from the Exhibit 6-1.

Exhibit 6-2 presents the film and processing costs per image and square mile for the three film sizes of interest: 35 mm used in 35 mm cameras, 70 mm used in the ENVIRO-POD, and 9.5 in. used in

Exhibit 6-1

IMAGES/SQUARE MILE AS A FUNCTION OF SCALE,
CAMERA AND TECHNIQUE*

Photographic Technique	30% sidelap (for coverage)			60% overlap (for steroscopic viewing) and 30% sidelap (for coverage)		
Scale	35 mm Camera	Photogrammetric Mapping Camera	ENVIRO-POD	35 mm Camera	Photogrammetric Mapping Camera	ENVIRO-POD
1:2000	800	20	98		32	157
1:4000	200	5	24	NOT	8	39
1:6000	88	2	11		4	17
1:8000	50	1	6	APPLICABLE	2	10
1:10,000	32	1	4		1	6

*Rounded to nearest whole number.
See Exhibit B-1.

$$\text{Images/square mile} = \frac{(\text{Scale})^2}{\text{Image Area } (\text{mi}^2)}$$

Image Size for Different Films

Camera	Image Area in.^2	mi^2
35 mm	2.0 in.^2	5.0×10^{-10} mi^2
Photogrammetric mapping	81 in.^2	2.0×10^{-8} mi^2
ENVIRO-POD	16.3 in^2	4.1×10^{-9} mi^2

Exhibit 6-2

FILM AND DEVELOPMENT COSTS/SQ. MILE
AS A FUNCTION OF SCALE, CAMERA AND TECHNIQUE
(COST/IMAGE X IMAGES/MILE)

Photographic Technique / Scale	30% sidelap (for coverage)		60% overlap (for steroscopic viewing) and 30% sidelap (for coverage)		
	35 mm Camera	Photogrammetric Mapping Camera	ENVIRO-POD	35 mm Camera	Photogrammetric Mapping Camera	ENVIRO-POD
1:2000	$800	$99.40	$129.36		$159.04	$207.24
1:4000	200	24.85	31.68	NOT	39.76	51.48
1:6000	88	9.94	14.52		19.88	22.44
1:8000	50	4.97	7.92	APPLICABLE	9.94	13.20
1:10,000	32	4.97	5.28		4.97	7.92

Cost/sq.mi. = Images/sq.mi. (from Exhibit 6-1) times cost/image (see tables below)

Camera	Film & Development Costs/Image
35 mm	$1.00
Photogrammetric Mapping	$4.97
ENVIRO-POD (70 mm film)	$1.32

Costs/image = cost/foot x feet/image

Assumptions	Film Type 70 mm	9.5"
Feet/roll	100'	125'
Feet/image	.625'	.924'
Film cost/roll	$125.50	$523.50
Film cost/foot	$1.26	$4.18
Processing	$26.22	$90.39
Chemical costs/roll		
Processing labor costs/roll	$60.00	$60.00
Processing costs/ft.	$0.86	$1.20
Total cost/ft.	$2.12	$5.30

Note: These costs of for illustration only.
Actual costs should be determined on a site specific basis.

conventional photogrammetric mapping cameras. Note that while the cost per image increases with film size, the more important figure, cost per square mile photographed, goes down as film size increases.

Costs per square mile photographed also decrease with scale, and increase when the images are overlapped to insure adequate coverage and to allow stereoscopic viewing. As discussed in Section 4.3 however the improvements in accuracy are worth the extra expense. Furthermore, because when either the ENVIRO-POD or standard mapping techniques are employed, the costs of film and processing comprise less than 3% of the CIR aerial survey costs, the extra images have only a small impact on total costs.

When color film is used in addition to CIR the film and processing costs double.

6.2.2 Flying Costs

EPIC estimates that the total flying costs usually are approximately $5.00 per image (1981 costs, Wolle, personnal communication). However, costs vary depending upon the following factors:

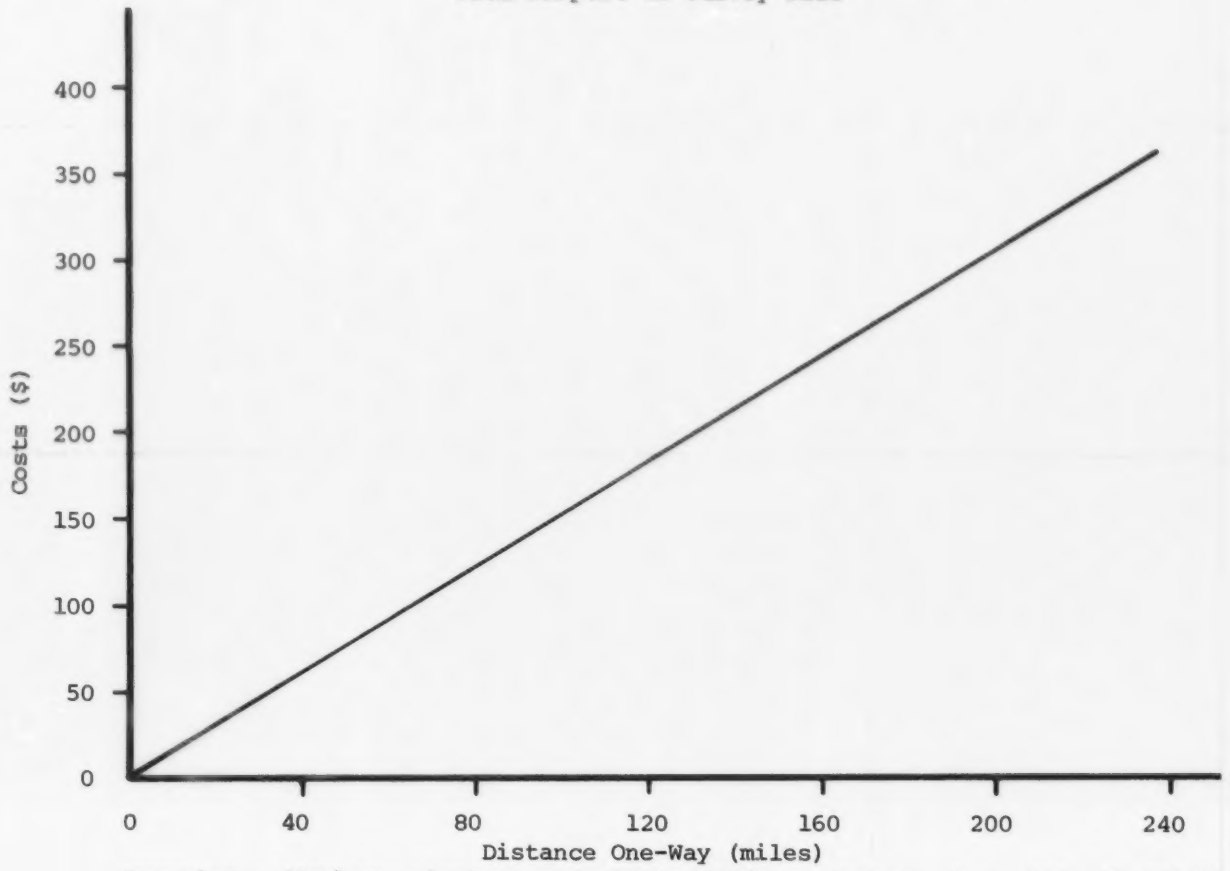
- the hourly rate of the pilot and airplane
- the hourly rate of the photographer
- the time required to fly to and from the survey site
- the time required to complete the photography.

An airplane and pilot usually cost $52 - $84 per hour, depending on the size of the plane (1981 costs, Wolle, personal communication). The smaller, single engine planes commonly used for aerial photography such as the Cessna 172 approved for the ENVIRO-POD fly at approximately 100 miles per hour. Larger planes, or twin engine planes fly somewhat faster. 100 mph is a typical air speed for use in CIR aerial surveys.

The costs of flying can be divided into two categories -- the mobilization costs and the actual surveying costs. Mobilization costs are the costs of getting the airplane to and from the survey site, and depend on the distance between the survey site and the base airport, aircraft speed, and hourly rates of the pilot and photographer. Exhibit 6-3 presents mobilization costs for different distances, assuming the standard labor rates, 100 mph flight speed and $52 per hour cost for airplane and pilot. It can be estimated according to the following formula:

$$C_m = 2D \times \frac{(Cpl + Cpm)}{MPH}$$

Exhibit 6-3
Mobilization Costs as a Function of Distance
From Airport to Survey Size



Assuming: $52/hour airplane and pilot; $24/hour photographer; 100 mph flight speed

Note: These costs are for illustration only.
Actual costs should be determined on a site specific basis.

where:

C_m = mobilization costs
D = distance between airport and survey site
MPH = aircraft speed
C_{pl} = hourly cost of plane and pilot
C_{ph} = hourly cost of photographer

Surveying costs are the costs of photographing the area and depend on the time required to complete the survey, the hourly rates of the staff involved, and hourly rates of the aircraft. The time required to complete the survey depends on flying speed, area size and the number of passes needed to obtain images with the desired sidelap, which in turn depends on the film width and photography scale. Appendix B presents the formula for calculating the flying times and Exhibit 6-4 presents the number of passes required to photograph the survey area, as a function of camera, scale and survey area. Exhibit 6-5 presents the survey costs per mile of survey area length as a function of the same factors.

When a 35 mm camera is used, the image size is so small that depending on housing density, individual photographs may only include from one to at most four yards. Positioning the airplane becomes more critical to good pictures, and flying time increases. One practioner reported that it took one hour and twenty minutes to photograph a 1.5 square mile area at approximately 1:4500 scale with a 35mm camera (Morlock, personal communication).

Because the ENVIRO-POD is located on the outside of the plane, and can only hold enough film to photograph a 22 square mile area, total flying costs would be doubled for survey areas greater than this size. Similarly, flying costs would double if color film was used in addition to CIR unless the ENVIRO-POD was used, or the aerial photographer was equipped with two cameras. Exhibit 6-6 presents the total costs of image acquisition (excluding mobilization costs) for different sized and shaped areas.

6.3 IMAGE INTERPRETATION

Image interpretation costs depend on the interpreter's hourly rate and overhead, as well as the time required to review the images. Research revealed two different estimates of the interpretation time requirements. EPIC estimates that it takes 8 hours to review a 55 square mile area photographed with a standard mapping camera, and 12-14 hours to cover the same sized area when an ENVIRO-POD is used (Crook, personal communication). This works out to $3.78/square mile for standard mapping cameras, and $5.67-$6.62/ square mile for the ENVIRO-POD assuming a $12.00 hourly and a 100% overhead rate. RSC estimates that it is possible to examine 400-500 yards in an eight hour day (Evans personal communication). Using the same wage and overhead rates, this works out to $0.38-$0.48/house.

Exhibit 6-4

NUMBER OF PASSES REQUIRED TO PHOTOGRAPH AN AREA OF GIVEN WIDTH AS A FUNCTION OF CAMERA AND SCALE

	Type of Camera	Width of Survey Area										
		1 mi	2 mi	3 mi	4 mi	5 mi	6 mi	7 mi	8 mi	9 mi	10 mi	
1:8000	Mapping	3	5	7	9	11	14	16	18	20	22	1:8000 Scale
1:8000	ENVIRO-POD	3	6	9	11	14	17	19	22	25	27	
1:8000	35 mm	15	29	43	57	71	85	99	113	127	141	
1:4000	Mapping	5	9	14	18	22	27	31	36	40	44	1:4000 Scale
1:4000	ENVIRO-POD	6	11	17	22	27	33	38	44	49	54	
1:4000	35 mm	29	57	85	114	142	170	199	227	255	283	

*Rounded to nearest whole number.
Assuming 30% sidelap.

$$\text{Number of Passes} = \frac{\text{Area Width}}{UW_i/\text{Scale}}$$

UWi = useable image width = .4 x image size

See Exhibit B-3.

Exhibit 6-5

COST OF FLYING OVER SURVEY AREA/LINEAR MILE
AS A FUNCTION OF SURVEY AREA WIDTH, CAMERA AND SCALE

	Width of Survey Area / Type of Camera	1 mi	2 mi	3 mi	4 mi	5 mi	6 mi	7 mi	8 mi	9 mi	10 mi
1:8000	Mapping	4.68	7.80	10.92	14.04	17.16	21.84	24.96	28.08	31.20	34.32
	ENVIRO-POD	4.68	9.36	14.04	17.16	21.84	26.52	29.64	34.32	39.00	42.12
	35 mm	23.40	45.24	67.08	88.92	110.76	132.60	154.44	176.28	198.12	219.96
1:4000	Mapping	7.80	14.04	21.84	28.08	34.32	42.12	48.36	56.16	62.40	68.64
	ENVIRO-POD	9.36	17.16	26.52	34.32	42.12	51.48	59.28	68.64	76.44	84.24
	35 mm	45.24	88.92	132.60	177.84	221.52	265.20	310.44	354.12	397.80	441.48

Assumes:

$52/hour for plane and pilot
$24/hour for photographer
100 mph
$1.56/mile

Flying cost/linear mile = Passes per area width (from Exhibit 6-4) times $1.56/mile (assumed flying cost).

Note: These costs are for illustration only.
Actual costs should be determined on a site specific basis.

Exhibit 6-6

TOTAL AERIAL PHOTOGRAPHY FLYING COSTS
(EXCLUDING MOBILIZATION FOR DIFFERENT SIZED AND SHAPED AREAS)

Area	Shape L x W	35 mm 1:4000	35 mm 1:8000	Envrio-Pod 1:4000	Envrio-Pod 1:8000	Std Mapping 1:4000	Std Mapping 1:8000
1 sq. mi.	1 x 1	$ 246	$ 73	$ 60	$ 18	$ 48	$ 15
2 sq. mi.	2 x 1	490	147	121	35	96	29
5 sq. mi.	5 x 1	1226	367	302	88	239	73
10 sq. mi.	5 x 2	2445	726	596	177	470	139
20 sq. mi.	5 x 4	4889	1445	1192	346	940	270
15 sq. mi.	5 x 3	3663	1085	898	265	709	205
30 sq. mi.	10 x 3	7326	2171	1795	530	1418	409
25 sq. mi.	5 x 5	6108	1804	1486	434	1172	336
Image cost/sq.mi.		$ 200	$ 50	$ 51	$ 13	$ 40	$ 10

Total Flying Cost = Length of area times flying cost/linear mile (from Exhibit 6-5), plus area times image cost/sq.mi. (from Exhibit 6-2, and listed above for convenience).

Note: These costs are for illustration only.
Actual costs should be determined on a site specific basis.

6.4 GROUND VERIFICATION

The costs of ground verification depend upon:

- o the number of yards that are checked
- o travel costs to and from the survey site
- o ground travel costs at the site
- o per diem costs
- o time requirements per house checked
- o hourly and overhead rates.

The number of yards reviewed depends upon the number of suspected failures, and the proportion of the suspected failures that are verified. EPIC for example will only visit 10% of the suspected failures whereas RSC will inspect each one. Assuming the standard labour and overhead rates, 40 houses/day (Evans, personal communication), $40/day ground transportation and $40/day per diem, the variable costs of the ground verification would run $7.00/house. The fixed costs of travelling to and from the site must also be included. Exhibit 6-7 presents the costs of ground verification if as a function of number of houses in the CIR aerial survey and rate of suspected failures assuming all suspected failures are inspected. The exhibit uses the variable costs described above and a fixed cost of $300.00 travel to and from the site, and assumes minimum of one day of labour and per diem expenses for any survey.

Costs can be calculated as follows.

The greater of:

$$C_{gv} + (C_O \times C_{gv})) + C_t + C_{pd} + C_{gt}$$

or

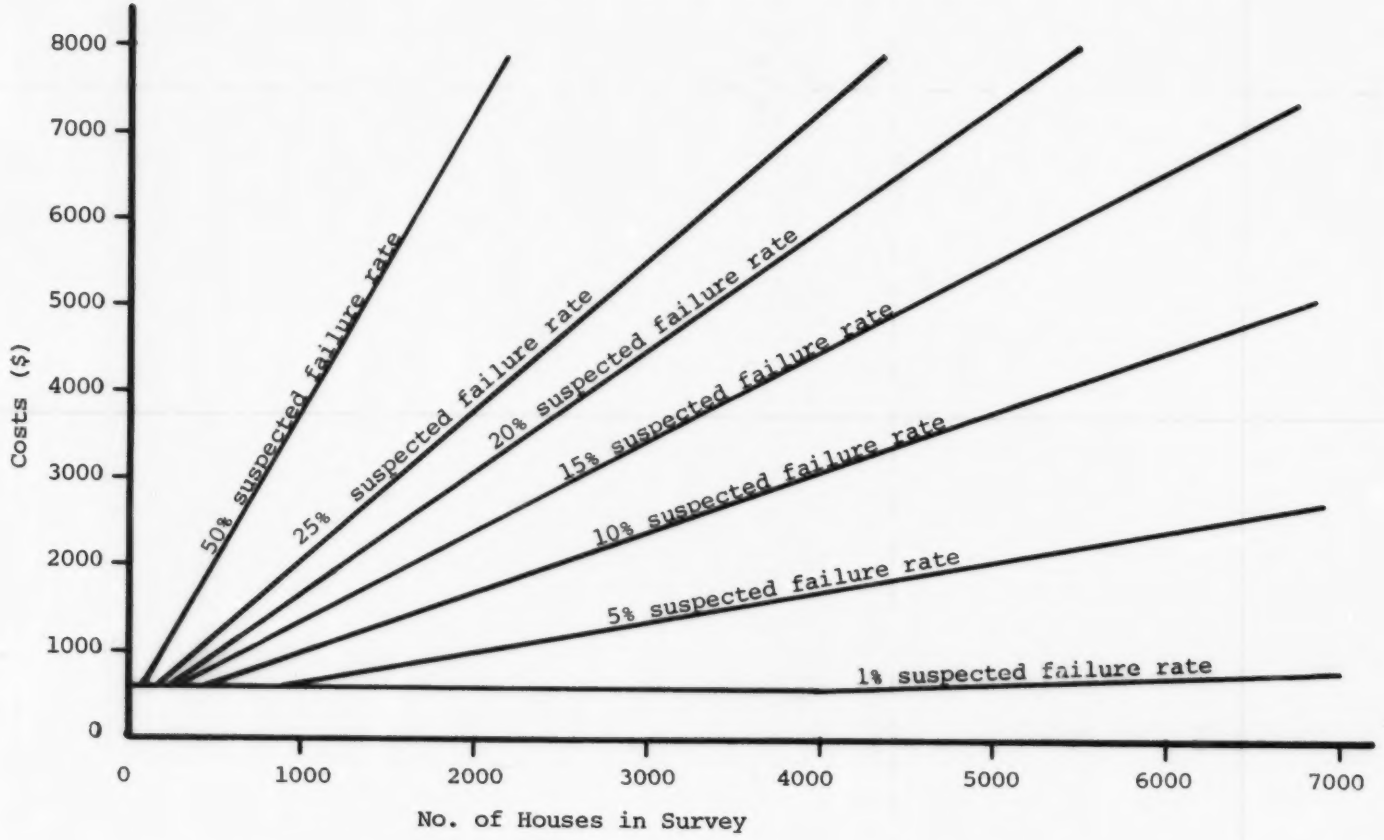
$$\frac{F \times H}{40} \times [(C_{gv} + (C_O \times C_{gv}) + C_{pd} + C_{gt}] + C_t$$

where:

- C_{gv} = daily rate of ground verifier
- C_O = daily overhead rate of ground verifier
- C_t = travel costs to and from survey site
- C_{pd} = per diem expenses
- C_{gt} = daily ground transportation costs
- F = suspected failure rate
- H = number of houses in the CIR aerial survey.

Depending on the costs, the agency or firm commissioning the CIR aerial survey may choose to verify the suspected failures itself, rather than relying on the surveying firm, provided the agency had trained staff available to do the work. The greatest savings would probably be in transportation and per diem costs.

Exhibit 6-7
Cost of Ground Verification by Number of Houses
In Survey and Suspended Failure Rate



Note: These costs are for illustration only.
Actual costs should be determined on a site specific basis.

6.5 REPORT WRITING

The costs of report writing depend on labour and overhead rates, and the amount of information included. RSC assumes that it takes approximately two person days to prepare a summary report, or using the standard labour and overhead rates, $416 (Evans, personal communication). EPIC includes a geologic and soils analysis, as well as information on the suitability of different areas for onsite systems, representative aerial photographs, and USGS maps with all suspected and confirmed failures identified on it in their final report. They assume that the preparation costs amount to $1450.

6.6 COST IMPLICATIONS

Exhibit 6-8 breaks down the theoretical costs of complete CIR aerial surveys by phases of the process using different sized areas and housing densities. Exhibit 6-9 presents costs on a wider range of area types. These costs are based on:

- 1:8000 scale
- constant survey preparation costs of either $384 (RSC) or $3840 (EPIC)
- constant mobilization costs of $100
- interpretation rates of 450 houses per day (35 mm and the standard mapping cameras) or 300 houses per day (ENVIRO-POD)
- failure rate of 10% with all suspected failures verified (RSC) or 10% of the failures verified (EPIC)
- constant report writing costs of $416 (RSC) or $1450 (EPIC)
- aerial photography costs based upon the number of passes required to completely photograph an area
- film processing costs based on 30% side lap on both sides for all cameras, and steroscopic viewing for ENVIRO-POD and standard mapping cameras only.

These assumptions are based on the best data available, and for comparative purposes only. Note that the estimated costs for the aerial photography for the 35 mm camera are probably low. The only experience with this photographic technique indicates that photographing a square mile took almost an hour, which would amount to $75 using the rates presented as opposed to $23. Note further that it is not possible to estimate the costs of larger areas by multiplying the per square mile cost of the number of square miles in the survey. This is because some costs are constant, aerial

Exhibit 6-8

BREAKDOWN OF THEORETICAL COSTS OF CIR OVERFLIGHTS FOR DIFFERENT SURVEY AREAS, AND USING DIFFERENT SURVEY TECHNIQUES

Camera	320 Houses/sq. mi.			640 houses/sq. mi.		
	35 mm	ENVIRO-POD	Standard	35 mm	ENVIRO-POD	Standard
Survey Preparation RSC (EPIC)	$ 384 (3840)	$ 384 (3840)	$ 384 (3840)	$ 384 (3840)	$ 384 (3840)	$ 384 (3840)
Film & Processing	50	13	10	50	13	10
Mobilization	100	100	100	100	100	100
Aerial Photography	23	5	5	23	5	5
Interpretation	138	213	138	276	427	276
Ground Verification 10% Failure Rate RSC (EPIC)	580 (580)	580 (580)	580 (580)	748 (580)	748 (580)	748 (580)
Report Preparation RSC (EPIC)	416 (1450)	416 (1450)	416 (1450)	416 (1450)	416 (1450)	416 (1450)
Total RSC (EPIC)	1691 (6181)	1711 (6201)	1633 (6123)	1997 (6318)	2093 (6415)	1938 (6260)
Cost/House RSC (EPIC)	5.28 (19.31)	5.39 (19.38)	5.10 (19.13)	3.12 (9.87)	3.27 (10.02)	3.03 (9.78)

See Exhibit B-4. These costs are for illustration only.

Exhibit 6-8 (continued)

BREAKDOWN OF THEORETICAL COSTS OF CIR OVERFLIGHTS FOR DIFFERENT SURVEY AREAS, AND USING DIFFERENT SURVEY TECHNIQUES

Camera	640 houses/sq.mi. (6400 houses) 10 sq.mi. (2 mi. L X 5 mi. W)			320 houses/sq. mi. (8000 houses) 25 sq. mi. (5 mi. X 5 mi.)		
	35 mm	ENVIRO-POD	Standard	35 mm	ENVIRO-POD	Standard
Survey Preparation RSC (EPIC)	384 (3840)	384 (3840)	384 (3840)	384 (3840)	384 (3840)	384 (3840)
Film & Processing	500	130	100	1250	325	250
Mobilization	100	100	100	100	100	100
Aerial Photography	222	45	35	554	109	86
Interpretation	2752	4267	2752	3440	5333	3440
Verification RSC (EPIC)	4780 (748)	4780 (748)	4780 (748)	5900 (860)	5900 (860)	5900 (860)
Report Preparation RSC (EPIC)	416 (1450)	416 (1450)	416 (1450)	416 (1450)	416 (1450)	416 (1450)
Total RSC (EPIC)	9154 (9612)	10,121 (10,579)	8566 (9024)	12,044 (11,494)	12,567 (12,017)	10,576 (10,026)
Cost/house RSC (EPIC)	1.43 (1.50)	1.58 (1.65)	1.34 (1.41)	1.50 (1.44)	1.57 (1.50)	1.32 (1.25)

See Exhibit B-4. These costs are for illustration only.

Exhibit 6-9

THEORETICAL CIR OVERFLIGHT SURVEY COST FOR DIFFERENT AREAS

	35 mm		ENVIRO-POD		Standard Mapping	
	Total $	$/house	Total $	$/house	Total $	$/house
1 sq. mi.						
320 houses RSC (EPIC)	$1691 (6181)	$ 5.28 (19.31)	$ 1711 (6201)	$ 5.35 (19.38)	$ 1633 (6123)	$ 5.10 (19.13)
640 hosues RSC (EPIC)	1997 (6318)	3.12 (9.87)	2093 (6415)	3.27 (10.02)	1938 (6260)	3.03 (9.78)
1280 houses RSC (EPIC)	2719 (6593)	2.12 (5.15)	2967 (6841)	2.32 (5.34)	2661 (6535)	2.08 (5.10)
1920 hosues RSC (EPIC)	3443 (6869)	1.79 (3.58)	3842 (7268)	2.00 (3.78)	3385 (6811)	1.76 (3.55)
10 sq. mi. (2mi.L x 5 mi.W)						
3200 houses RSC (EPIC)	5538 (8068)	1.73 (2.52)	5747 (8277)	1.80 (2.59)	4950 (7480)	1.55 (2.34)
6400 houses RSC (EPIC)	9154 (9612)	1.43 (1.50)	10,121 (10,579)	1.58 (1.65)	8566 (9024)	1.34 (1.41)
25 sq. mi. (5 mi. x 5 mi.)						
8000 houses RSC (EPIC)	12,044 (11,494)	1.50 (1.44)	12,567 (12,017)	1.57 (1.50)	10,576 (10,026)	1.32 (1.25)
16,000 houses RSC (EPIC)	21,084 (15,494)	1.32 (0.97)	23,501 (17,911)	1.47 (1.12)	19,616 (14,026)	1.23 (0.88)

See Exhibit B-4. These costs are for illustration only.

photography costs are a function of area size and shape, film costs depend on area size only, and interpretation and ground verification costs vary with the number of houses.

The exhibits indicate that cost per house drops with density and area size. RSC's approach (low level of effort for survey preparation and report writing, but ground verification of all suspected failures) is less expensive than EPIC's (high level of effort for report writing and survey preparation, only 10% of failures inspected) in all but the 25 square mile areas with housing densities of one house/acre or one house/two acres. RSC's approach becomes more expensive than EPIC's when there are a large number of houses in the survey because RSC inspects all suspected failures rather than only 10%. In a survey area with 8,000 houses and a 10% suspected failure rate, RSC would inspect 800 houses at a cost of $5,900 as opposed to EPIC which would inspect 80 houses at a cost of $860. In areas with fewer houses, EPIC's increased costs of survey and report preparation, and image interpretation outweigh their cost savings from verifying only 10% of the suspected failures.

The two survey approaches result in different information. The extra costs of ground verifying all suspected failures must be borne if all failures must be identified. However, in this case there is little need to obtain and analyze extensive amounts of background data, and report writing requires less labor. On the other hand, extra effort in survey preparation and report writing is required in order to insure accurate image interpretation if all suspected failures are not inspected and the surveyor's purpose is to assess the area's general suitability for onsite wastewater disposal.

Surveys are less expensive using standard mapping cameras than using ENVIRO-POD or 35 mm cameras. These differences while not large in small areas, are substantial in larger areas.

CHAPTER 7

USING CIR AERIAL SURVEYS

7.1 ISSUES CONCERNING THE USE OF CIR AERIAL SURVEYS

Potential clients of CIR aerial surveys should consider the following issues in deciding whether or not to commission a survey, and the extent of the services required:

- o type of onsite system failures of concern
- o other types of onsite system surveys that are required
- o characteristics of the survey area
- o survey purpose
- o comparative costs.

7.1.1 Types of Failures of Concern

The first and most important issue to resolve is the type of failures that are expected in the survey area. CIR aerial surveys can only identify systems where septic tank effluent is rising to the soil surface rather than percolating down to the groundwater. These surveys cannot reveal on-site systems that are failing to treat the wastewater adequately and polluting ground or surface waters. Nor can CIR aerial surveys identify onsite systems that are backing up into owners' homes. CIR aerial surveys are not useful if these two latter kinds of failure are the major concerns.

7.1.2 Other Surveys Required

CIR aerial surveys may not be appropriate even if surfacing SAS's are a major concern. If it is necessary to conduct thorough door to door inspections or surveys to identify systems that are not treating the wastes adequately or are backing into homes, questions concerning surfacing and a visual inspection of the yard can easily be included in the investigation. In such an instance, a CIR aerial survey would be redundant. Mailed questionaires will not usually substitute for CIR aerial surveys however, because the response rate and the accuracy are frequently unacceptable.

7.1.3 Characteristics of the Survey Area

A number of factors about the survey area may reduce the value and effectiveness of CIR aerial surveys. First, if the area is heavily forested with evergreens, the trees may obscure many failing systems. Similarly, if the area contains mostly summer homes, and is heavily wooded with deciduous trees, the trees will be in leaf, blocking the failure signatures at the times when the homes would be occupied and the failures evident.

Another issue of concern is area size. If the community is small enough, it may be less expensive to do a house to house survey. The cut off size varies depending upon labor rates, and failure rates. The client should briefly analyze these issues before deciding to commission a CIR aerial survey. Judging from our hypothetical analysis (see Exhibit 6-9) one square mile area of 320 houses on 2 acre lots with a 10% failure rate would cost $5.20 (RSC approach) per house and probably would be worth surveying. If the density increased to one house per acre (640 houses), the per house price would drop to about $3.00. If the failure rate increased to 50% however, the per house cost in the 320 house area would jump to $7.70, and might not be worth it. In such a case, inspecting every house may be less expensive than using CIR aerial photography and only inspecting the houses with suspicion signatures. The EPIC approach is not cost effective in a one-square mile area unless the density is at least 2 houses/acre.

The location of the survey area is also important. If the area is far removed from an airport that rents airplanes, or if it is distant from a professional aerial photographer, mobilization costs may make the survey prohibitively expensive. Photography must occur on clear days a few days after rainfall. The farther the site is from the aerial photographer's home base, the more difficult and costly it becomes to arrange for the aerial photography when the weather conditions are appropriate.

Finally, time constraints and labor availability must be considered. In some situations, CIR aerial surveys may be the only option that can provide the data quickly enough.

7.1.4 Survey Purpose

The purpose of the survey affects the amount of background data that should be collected and the extent of the ground verification required. If the purpose of the survey is to identify every surfacing SAS in the study area, in order to document the need for centralized treatment, for example, all suspected failures must be inspected. However, the amount of background data that must be collected is not that extensive.

If the CIR aerial survey is used to identify pockets of problems, or assess the general suitabilty of the region for onsite systems, detailed background information on soils, system design, and installation practices is needed in order to determine if the failures are caused by natural conditions or system construction or design. However, when soils and design conditions are well documented, each suspected failure may not have to be verified. Provided he or she has enough background data, the image interpreter may only have to inspect a proportion of the systems in order to make certain that interpretation key was accurate and the images had been interpreted correctly. These systems must be selected to be representative of soil types, or different construction practices, or clusters of failures. But unless all suspected failures are inspected, it is not possible to quantify the exact number of failing SAS's.

7.1.5 Costs

In some situations, other surveying techniques may cost less than CIR aerial surveys. Similarly, it may be less expensive for the client to complete parts of the survey in-house, rather than relying on the services of the CIR aerial survey firm for the entire survey. Comparative costs can be estimated using the approach presented in Chapter 6 or the client can ask surveyors for bids on the cost of completing a survey.

Theoretically, almost any aspect of the survey could be completed by the client. However, in practice, it might not be feasible or practical for the client to participate in all phases. The client may be able to obtain, or already have, the background information needed to plan the survey and interpret the signatures. However, the data must be analyzed by the photographer and interpreter. Because aerial CIR photography and interpreting the signatures of surfacing SAS's requires extensive experience, it is unlikely that the client will be able to successfully perform these tasks in-house.

The most likely role for the client would be in the ground verification process. It may be less expensive for the client to perform the inspections than the interpreter, depending on labour rates, travel costs, and the availability of trained personnel. However, the interpreter must do the ground verification when the survey is being used to assess the suitability of the area for onsite systems and only representative yards are inspected. The interpreter must inspect the systems personally to be able to reevaluate the images in light of the actual correlation between the signatures and the functional status of the SAS's. The client would not be qualified to reinterpret the images on the basis of the information gained from the inspections.

7.2 COMPLETING A CIR AERIAL SURVEY

Once it has been determined that a CIR aerial survey is appropriate, and the scope of services has been decided upon, the client should make the necessary arrangements to contract any or all of the following tasks: background data collection and analysis, aerial photography, film development, image interpretation, ground verification, and report writing. The procedures discussed in Chapter 4 and outlined below should be used.

7.2.1 Survey Preparation

Background data on soils and system design and a map of the survey area should be obtained. The information should first be analyzed to determine the flight window. The survey should be conducted when the SAS's are most likely to fail; that is, when groundwater is at its maximum height and the systems are in use. In addition the signs of failure must be visible from the air: lawn vegetation must not be dormant, the leaves should be off the trees, and the sun angle should be at a maximum so that shadows are minimized. These conditions are most easily met midday, in the early spring or late fall.

The specific date depends on the weather conditions. The sky should be clear, and there should be no standing water on the ground from recent rainfall. Since it is impossible to predict when these conditions will occur, several alternate flight dates should be scheduled, and the pilot and photographer should be prepared to fly on short notice.

The photographer and pilot should use the available maps and data on the survey site to lay out the flight plan in advance of the survey date.

7.2.2 Image Acquistion

As discussed in more detail in Section 4.3 standard photogrammetric mapping techniques should be used. The equipment and procedures are standard, any experienced aerial photographer could perform this part of the survey. CIR film is readily available and can be processed in-house or at several laboratories around the country. Although various practitioners of CIR aerial surveys disagree somewhat about proper equipment and technique, research indicated that the following procedures offer the best survey results.

- Film CIR is the film of choice, and Kodak aerochrome 2443 is the only low altitude aerial CIR film available. CIR film costs the same as color film and is far more sensitive to the signs of surfacing SAS's.

- Cameras Standard photogrammetric mapping cameras used by aerial photographic firms provide the least costly coverage of the survey area. Flying time, film costs, and interpretation costs increase if 35 mm cameras or EPA's ENVIRO-POD camera system is used. Although the ENVIRO-POD has two cameras and can simultaneously expose both color and CIR film, this advantage is not needed by experienced interpreters. Filters must be used with CIR film to screen out blue wavelengths. Wratten 12 filters provide the best contrast.

- Photography Standard photogrammetric mapping procedures give the best results for the lowest price. These include 60% image forward lap for stereoscopic viewing and 30% sidelap on each side to insure coverage of the area.

- Scale Scale is the ratio of the distance on the film to distance covered on the ground. It is calculated the ratio of lens focal length to the altitude of photography. Because the number of images required to cover an area increases with the square of the increase in scale, it is important to keep the scale as small as possible to minimize costs. However, scales should be as large as possible to maximize ground resolution. Experience with CIR aerial surveys indicates that image interpretation becomes inaccurate at scales smaller than 1:8000, and does not increase at larger scales.

7.2.3 Image Interpretation

Interpretation involves analyzing the images and identifying possible failing systems. Color transparencies should be analyzed using a light table, and a standard pocket stereoscope with four-fold magnification.

Although standard image interpretation techniques and equipment are used, experience with CIR aerial surveys indicates that interpreters must be familiar with CIR film, SAS design, and the CIR photographic signatures of surfacing SAS's. Inexperienced interpreters may miss failing systems and may mistake properly operating SAS's for failing systems.

7.2.4 Ground Verification

Once the images have been interpreted the suspected failures should be inspected to make sure that image interpretation was accurate. The proportion to be inspected depends on the purposes of the survey. The task should be peformed as soon after the survey as feasible, so that conditions are as similar as possible to those at the time of the photography.

7.2.5 Report Writing

The results must be packaged in a form that is useful to the client. The report may stand on its own or be a part of a larger planning document. It's contents depends upon the use to which the survey will be put. The client should negotiate with the surveyor, the amount and type of data included and the format prior to executing a contract.

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APPENDIX A

INDIVIDUALS INTERVIEWED CONCERNING CIR AERIAL SURVEYS

Carl Altenbernd	Lake Aggasiz Regional Council, Fargo, ND
Jeff Barnes	EPA Region III
John Bellchler	Mid States Engineering Company, Inc., Indianapolis, IN
Mike Cliburn	Mays Sudderth & Etheredge, Orlando, FL
Bob Cooper	EPA Region IV
Norm Crisp	EPA Region VII
Dennis Crook	EPIC, Warrenton, WV
Carl Delory	EPA Region I
Gerald Esposito	Delaware Department of Natural Resources, Wilmington, DE
Barry Evans	Remote Sensing Consultants, State College, PA
Dennis Fewless	N.D. Water Supply & Pollution Control Agency, Bismark, ND
Ray Filby	EMSL, Las Vegas, NV
Rebecca Flack	EPA Region IV
Spencer Franklin	Ann Arundel County Health Dept, MD
Phil Fredericks	Clyde Williams and Associates, South Bend, IN
Mary Jo Garris	Maryland State Health Deptartment, Annapolis, MD
Kathy Garrow	EPA Region IV
Susan Grayson	North Carolina Health Department, Durham, NC
Dr. Wendell Hovey	South Dakota School of Mining Tech., Rapid City, SD
Alex Hull	Boyer Singleton Associates, Orlando, FL
Vern Johnson	EMSL
Ralph Keefer	University of Wisconsin, Madison, WI
Jack Krantsmeyer	EPA Region V
Clint Lumsden	University of Mass. Suburban Experimental Field Station, Waltham, MA
Bill Markley	S.D. State Health Agency, Pierre, SD
Bob Mikulik	EPA Region IV
Bud Morlock	Flying Camera, Inc., Enon, OH
Tony Neville	Gannett & Fleming, Harrisburg, PA
John Otto	Eastman Kodak, Rochester, NY
Martin Pane	EPA Region VIII
Rich Papina	EPA Region III
Rick Pavey	LARS, Indianapolis, IN
Ron Peales	Jacobs Engineering, Johnson City, TN
Gary Peterson	Pennsylvania State, State College, PA
Sheldon Phillips	Eastman Kodak, Rochester, NY
Bob Pollack	EPA Region VII
Evelyn Shultz	EPA Region II
Terry Slonecker	EPIC
Marilyn Slobadoshka	EPA Region V
Gunnar Sreibers	METRO Seattle, WA
Mike Stallard	Metcalf & Eddy, Boston, MA
Paige Strailey	North Carolina State Health Dept., Durham, NC
Mike Strub	Rapid City, S.D., 208 Planning Agcy.
Estol Swen	Giffelo-Webster Engineers, Pontiac, MI
Dale Swoboda	East-West Gateway Coordination Council, Kansas City, MO
Rochelle Volin	EPA Region III
Wes Wilson	EPA Region VIII
Frank Wolle	EPIC, Warrenton, WV
Paul Yaniga	Groundwater Technology Inc., State College, PA

APPENDIX B

CALCULATIONS

Exhibit B-1

Relating scale derivation of formula to the area covered in an image

Scale is a film unitless proportion: it is the ratio of the units of length in the exposed image (Li) to the units of length on the ground (Lg). Thus the distance photographed on the ground equals the length on the photograph divided by the scale. The area covered in the particular image (Ai) equals the width of the photograph (Wi) times the length of the photograph (Li).

Scale = Li/Lg, therefore,
Lg = Li/Scale

Ai = Li X Wi
Area on the ground (Ag) = Lg X Wg

Substituting:

Ag = Li/scale X Wi/scale, or,
Ag = Li Wi/scale^2

Also:

Ag = Ai/scale^2, or, Ai = Ag X scale^2

Example Calculations for Exhibits 4-2 and 6-1

For this example, use scale = 1:4000, and the photogrammetric camera film.

Given: Image Area (Ap) = 9" X 9" = 81 in^2 = 2.0 X 10^{-8} mi^2 per photo
Ground Area (Ag) = 1 mi^2

1) No Overlap =
Total image area needed (Ai) = Ag X scale^2
Ai = 1 mi^2 X $(1/4000)^2$ = 6.25 X 10^{-8} mi^2
Number of photos needed (N) = Ai/Ap
N = 6.25 X 10^{-8} mi^2/2.0 X 10^{-8} mi^2 per photo = 3.1 photos

2) 30% Sidelap (each side):
3.1 photos X 1.6 = 5.0 photos

3) 30% Sidelap + 60% overlap (forward only):
5.0 photos X 1.6 = 7.9 photos

Exhibit B-2

The relationship between film sensitivity
in lines per millimeter (LPM) and scale to ground resolution

Each line resolved is equal to the line and an associated blank space of equal width -- a so-called line pair. The length of each line is 5 times its width or, 2.5 times the width of the line pair.

Resolving power is tested using a set of three such line pairs under conditions of low and high contrast. Contrast is the antilog of the difference of the densities of the space and bars. 1.6 is a low test to object contrast, typical aerial photography with some haze. In this case the density difference of the bars and spaces would be 0.2. High test to object contrast is 100:1. This is considered infinite contrast (Eastman Kodak, 1976a). An area the size of one line pair can be distinguished on an image, and is a "ground resolved unit". It is possible to detect an area the size of one ground resolved unit but recognizing the object takes several ground units (Crouch, unpublished masters thesis).

$$GRU\ (mm^2) = 2.5/(Scale^2 \times LPM^2)$$

where:

GRU = ground resolved unit in mm^2
LPM = lines per millimeter

This formula is derived as follows:

$Wi/Wg = Scale$
$Wi = Scale \times Wg$

where:

Wg = width of the ground
Wi = width of the exposed image

The width of a line pair on a photograph = (LPw) = 1/LPM

substituting LPw for the width of the photograph

$LPw = Scale \times Wg$ or
$Wg = LPw/Scale$

Since the line pairs are 2.5 times as long as wide
$GRU = LPw/Scale \times 2.5(LPw/scale)$

Substituting LPM for LPw
$GRU\ (mm^2) = 2.5/(Scale^2 \times LPM^2)$

Exhibit B-3

Calculation of Flight Times

UWi = [1-(2 X % sidelap)] X Wi

NP = Wa/(UWi/Scale)

FT = NP X (La + PL)/ FS

Where:

FS = flight speed
FT = flight time
La = Length of survey area
NP = number of passes
PL = Flight distance needed to set up pass approach
Scale = Wi/Wa
UWi = usable width of the exposed image
Wa = Width of the survey area
Wi = Width of exposed image

Exhibit B-4

Calculations for Exhibits 6-8 and 6-9

These costs are for illustration only. Actual costs should be determined on a site specific basis.

I. As stated in section 6.6, several costs are assumed to be constant:

Survey preparation:	$384 for RSC
	$3840 for EPIC
Mobilization:	$100
Report preparation:	$416 for RSC
	$1450 for EPIC

II. Film and processing costs depend only on area size and can be taken from Exhibit 6-2. For 1:8000 scale, film and processing costs are:

Camera	Cost
35 mm	$50/sq.mi.
Enviro-Pod	$13/sq.mi.
Std. Mapping	$10/sq.mi.

III. Aerial photography costs depend only on area size and shape and can be derived from Exhibit 6-5. For 1:8000 scale, aerial photography costs are:

		Costs	
Camera	1sq.mi.	2mi. X 5mi.	5mi. X 5mi.
35 mm	$23.40	2 X $110.76	5 X $110.76
Enviro-Pod	$4.68	2 X $21.84	5 X $21.84
Std. Mapping	$4.68	2 X $17.16	5 X $17.16

IV. As discussed in section 6.3, interpretation costs depend only on the interpreter's time (i.e. salary and overhead costs), which depends only on the number of houses in the survey. For the 35mm and standard mapping cameras, the costs are calculated using $0.43 per house (per section 6.3). Costs for the Enviro-Pod are calculated using $200 per day (per section 6.3) and 300 houses per day. Stated as formulas, interpretation costs are calculated as:

35mm and standard mapping:

$$\text{Cost} = (\text{no. of houses}) \times \$0.43/\text{house}$$

Enviro-Pod:

$$\text{cost} = \frac{(\text{no. of houses})}{(300\ \text{houses/day})} \times \$200/\text{day}$$

V. Ground verification costs depend only on the number of houses and are discussed in secion 6.4. RSC costs assume checking 10% of all houses and EPIC costs assume checking 1% of all houses (assuming 10% failure rate). The ground verification costs are calculated using a $300 fixed cost per survey, plus $280 per day ($200 salary& overhead, $40 travel, $40 perdiem), and 40 houses visited per day. The minimum cost is assumed to be $580 ($300 fixed, plus $280 for one day). Costs for surveys of more than one day are calculated as follows:

$$\text{cost} = \frac{(\text{No. of houses visited})}{40\ \text{houses/day}} \times \$280/\text{day} + \$300/\text{survey}$$